TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Stoneman Lake is a 120 acre natural lake in the Coconino National Forest of central Arizona. The 900 acre watershed is primarily pine forest covering moderate to high slopes, with a 70 home development on the eastern side of the lake. Stoneman Lake is relatively shallow (<3.5 m), has no surface outlet, and is designated as cold-water fishery. The lake has historically experienced an abundant growth of submerged aquatic vegetation (SAV) during the warm weather months, with resulting vertical stratification and hypoxia in the lower water column. The lake is currently on Arizona's 303(d) list as impaired for dissolved oxygen (D.O.), pH, and the narrative criteria for nutrients. This study was undertaken to evaluate the following seven different lake/watershed management alternatives with regard to water quality benefit, feasibility and costs:

1. SAV harvesting/cutting
2. Herbicide application
3. Biological controls
4. CCC ditch regulation
5. Dredging
6. Septic system upgrades
7. Aeration

Three different models were developed to simulate Stoneman Lake and its watershed. The hydrologic/watershed loading model predicted moisture and nutrient fluxes to Stoneman Lake from direct precipitation, runoff, groundwater discharge, and septic systems. The U.S. Army Corps of Engineers model BATHTUB was used to simulate internal lake water quality dynamics. The U.S. Army Corps of Engineers SAV model that was originally developed for the Chesapeake Bay was applied to Stoneman Lake in a simplified manner to predict peak SAV biomass. In conjunction with computer modeling, the costs and feasibility of each of the alternatives were evaluated.

Model results show that Stoneman Lake receives most of its average annual nitrogen load from direct precipitation, whereas direct precipitation and runoff/groundwater flow contribute approximately equal proportions of the annual phosphorus load. Because it has no surface water outlet, Stoneman Lake water and chemical constituents have very long residence times compared to most other lakes. SAV obtain most of their nutrients from internal recycling.

Results of the alternative analysis indicate that regulation of the CCC ditch would provide a long-term water quality benefit at a moderate cost and reduce the frequency of the lake going dry. Although SAV growth would not be significantly inhibited, the SAV-related BOD would be diluted in a larger volume of water and D.O. concentrations would increase in the mid-to-upper portion of the water column. The major challenges to ditch regulation are the need to resolve the water rights and to identify a governmental entity willing to assume a leadership role.

Various methods of removing SAV from the lake (harvesting, biological controls, herbicide application) were predicted to significantly increase the algal biomass in Stoneman Lake and result in no reduction in total biological oxygen demand (BOD). However, these alternatives were also predicted to improve vertical mixing of the lake and thus provide more D.O. to the lower water column. If partial implementation revealed a net benefit to the lake, biological controls would be the most cost-effective means of reducing SAV growth.

Septic system upgrades were predicted to have little impact on SAV growth and water quality in the lake's present condition, largely due to the predominance of other nutrient sources and the fact that SAV growth will be more limited by self-shading than by nutrients. However, septic system upgrades would cause some reductions if algal growth if Stoneman Lake became algal-dominated, and would also reduce health risks from pathogen transmittal. Dredging and aeration/circulation are not practical in Stoneman Lake due to high costs and feasiblity problems.

1.0. BACKGROUND & PROBLEM STATEMENT

1.1 Description of TMDL Process

The Clean Water Act (CWA) establishes a national goal of "fishable", swimmable@ waters. In cases where waters do not meet this goal, Section 303(d) of CWA requires States to develop Total Maximum Daily Loads (TMDLs), with oversight from the Environmental Protection Agency (EPA). A TMDL allocates pollution control responsibilities among pollution sources in a watershed and is the basis for taking the actions needed to restore a waterbody.

High quality water is an extremely valuable commodity in Arizona. Water quality standards are established to protect the designated uses of Arizona′s waters. When States and local communities identify problems in meeting water quality standards a total maximum daily load (TMDL) can be part of a plan to fix water quality problems. The purpose of this TMDL study is to provide the local community, land and resource managers, ADEQ and U.S. EPA Region 9 with technical information that can be used to develop a water quality plan.

A TMDL represents the total load of a pollutant that can be discharged to a water body on a daily basis and still meet the applicable water quality standard [assumed to be the existing standard(s)]. The TMDL can be expressed as the total mass or quantity that can enter the water body within a unit of time. In most cases, the TMDL determines the allowable pounds per day of a constituent and divides it among the various contributors in the watershed as waste load (i.e., point source discharge) and load (i.e., nonpoint source) allocations. The TMDL must account for natural background sources and provide a margin of safety. For nonpoint sources such as accelerated erosion or internal nutrient cycling, it may not be feasible or useful to derive a pounds per day figure. In such cases, a percent reduction in pollutant loading may be proposed.

When sufficient information is lacking, a load analysis may take the form of a phased TMDL. A phased approach is being taken to this TMDL to effectively work toward 1) a better understanding of seasonal constraints to the ecosystem and 2) to more effectively build monitoring and management plans for the lake and watershed.

In Arizona, as in other states, changes in standards or the establishment of site-specific standards are the result of ongoing science-based investigations or changes in toxicity criteria from EPA. Changes in designated uses and standards are part of the surface water standards triennial review process and are subject to public review. Standards are not changed simply to bring the waterbody into compliance, but are based on existing uses and natural conditions. If deemed appropriate, investigation of the applicability of existing standards may be incorporated into a phased TMDL sample plan.

TMDLs must include specific information to be approved by U.S. EPA Region 9. This information can be summarized in the following eight elements:

Plan to meet State Water Quality Standards: TMDL includes a study and a plan for the specific water and pollutants that must be addressed to ensure that applicable water quality standards are attained.

Describe quantified water quality goals, targets, or endpoints: The TMDL must establish numeric endpoints for the water quality standards, including beneficial uses to be protected, as a result of implementing the TMDL. This often requires an interpretation that clearly describes the linkage(s) between factors impacting water quality standards.

Analyze/account for all sources of pollutants. All significant pollutant sources are described, including the magnitude and location of sources.

Describe the linkage between water quality endpoints and pollutants of concern. The TMDL must explain the relationship between the numeric targets and the pollutants of concern. That is, do the recommended pollutant load allocations exceed the loading capacity of the receiving water?

Develop margin of safety that considers uncertainties, seasonal variations and critical conditions. The TMDL must describe how any uncertainties regarding the ability of the plan to meet water quality standards that have been addressed. The plan must consider these issues in its recommended pollution reduction targets.

Provide implementation recommendations for pollutant reduction actions and a monitoring plan. The TMDL should provide a specific process and schedule for achieving pollutant reduction targets. A monitoring plan should also be included, especially where management actions will be phased in over time and to assess the validity of the pollutant reduction goals.

Include an appropriate level of public involvement in the TMDL process. This is usually met by publishing public notice of the TMDL, circulating the TMDL for public comment and holding public meetings in local communities. Public involvement must be documented in the state's TMDL submittal to EPA Region 9.

1.2 Water Quality Standards, 305(b), 303(d) and Impairment

Water quality standards for surface waters are reviewed and revised by states every three years as criteria are refined. These criteria, or threshold levels, are developed for various potential pollutants based on the particular designated uses of a waterbody and the degree of exposure or risk to humans, animals and plants. Standards may be numeric or narrative, meaning they can be numbers, ranges of numbers, or narrative descriptions. Arizona Surface Water Quality Standards contain both numeric and narrative criteria.

Every two years, each state must submit an accounting of how well their water bodies are meeting their standards (criteria). This report is known as the Water Quality Assessment Report or “305(b) Report”, after the section of the Clean Water Act that requires the account. Waters have been classified as “full support”, “threatened” (a subcategory of full support), “partial support” and “non-support.” Based on the 305(b) Assessment Report, the state generates a list of “impaired waters” from a review of the “partial” and “non-support” categories. The list is referred to as the “303(d) List” (CWA section).

Stoneman Lake was included on Arizona′s 1998 Water Quality Limited Waters List (303(d) List for three stressors: numeric pH, numeric dissolved oxygen and narrative nutrient standards. The lake was listed in 1998 based on data collected by the ADEQ Clean Lakes Program between 1995 and 1997. Violation of the narrative nutrient standard relates to the growth of excess aquatic weeds, which, in association with low DO and high pH, is interpreted as impairment of the aquatic and wildlife designated use and possible recreational uses. Stoneman Lake is designated for the following uses under Title 18, Chapter 11 of the Arizona Administrative Code:

A&Wc: Aquatic and wildlife uses, *coldwater fishery;
FBC: Full body contact;
FC: Fish consumption;
AgI: Agricultural irrigation; and
AgL: Agricultural livestock watering

* The designation of Stoneman as a cold-water fishery is under review in the 2000 Triennial Review. The lake is not stocked with salmonids and the AGFD reports that it is really a cool-water fishery. Beceause there is no such designation in the standards, the more appropriate designation may be ”warm water” fishery, which would revise the expectation for dissolved oxygen to 6.0 mg/L

The standards that currently pertain to Stoneman Lake include: pH in a range of 6.5 SU to 9.0 SU (all year, all portions of the water column), dissolved oxygen no lower than 7.0 mg/L or 90% saturation within the top 1 meter of the water column and a narrative standard which in relevant part reads:

> Surface waters shall be free from pollutants in amounts or combinations that ... cause the growth of algae or aquatic plants that inhibit or prohibit the habitation, growth, or propagation of other aquatic life or that impair recreational uses ...

1.3 Lake and Watershed Overview

Stoneman Lake is an approximately 120-acre natural lake located approximately 40 miles south of Flagstaff, Arizona in the Coconino National Forest (Figure 1-1). The lake has been placed on Arizona's 303(d) Total Maximum Daily Load (TMDL) Priority List for violations of water quality standards for dissolved oxygen (D.O.), pH and the narrative standard for nutrients. In March 2000, the Arizona Department of Environmental Quality (ADEQ) initiated a study to model the hydrology and water quality of Stoneman Lake and evaluate various implementation scenarios. This report describes the available data, methodology and results of the this effort.

1.3.1 Lake Characteristics

Stoneman Lake occupies a bowl-shaped depression on the Mogollon Rim of central Arizona (Figure 1-2) that has alternately been interpreted as a volcanic caldera (McCabe, 1971; Hasbargen, 1993) or a sinkhole that formed from the dissolution of limestone in a fault zone (Dohm, 1995). It has no surface water outlet. The lake is currently designated as a cold-water fishery and has populations of northern pike and yellow perch that are managed by the Arizona Game and Fish Department (AGFD). Although Stoneman Lake is a public water, a portion of the lake on the eastern side is privately owned. Stoneman Lake is not used as a water supply.

Lake depth varies considerably with year and season, but the lake is usually relatively shallow. A bathymetric survey performed by ADEQ in the spring of 1999 found an average depth of about 1.8 m (six feet) and a maximum depth of 2.5 m (8.2 feet). The lake goes dry when the water level drops below about 6714 feet above sea level (asl) The maximum lake level on record, which occurred in the spring of 1980, is about 6730 feet asl.

During the 1950s, a property owner dredged a portion of the eastern side of the lake and created a dike system and several impoundments within the lake (Figure 1-3). The top of the dike is at about 6726 feet asl. The depth of water within the impoundments is unknown, but they are probably deeper than the average lake depth. The water level in the impoundments is usually higher than that in the lake, and thus water flows into the lake by way of seepage through the dike.

During the warm seasons, Stoneman Lake has historically contained abundant emergent and submersed vegetation. Thick bullrushes grow on the perimeter, and submersed aquatic vegetation (SAV) such as Eurasian milfoil (*Myriophyllum spicatum*) and coontail (*Ceratophyllum demersum*) grow in profusion in the lake. It has been reported that during the summer, more than 90% of the lake surface area supports SAV growth.

FIGURE 1-1

Figure 1-2

Figure 1-3

Table 1-1

Figure 1-4

Water Quality:
The primary sources of water quality data for Stoneman Lake are sampling performed by AGFD and ADEQ during the years 1985-1987 and by the ADEQ Clean Lakes Program in 1995-1999. Table 1-1 provides a statistical summary of the sampling results for D.O., pH, chlorophyll and nitrogen and phosphorus species. Examination of the water quality data by season reveals that violations of the D.O. standard for cold-water fisheries (7 mg/L or 90-percent saturation) are restricted to summer months, when there is often a marked D.O. stratification in the lake (Figure 1-4). The lake is unstratified during other seasons. In contrast to seasonal patterns in D.O., pH is above eight year-round, although violation of the standard (6.5-9 standard units) are more frequent during the warm months. Although nutrient concentrations are only moderate, they exceed the narrative nutrient criteria because they are sufficient for supporting the abundant growth of SAV.

Chlorophyll concentrations are usually less than 5 µg/L, even during the summer months, indicating relatively low algal biomass. Similarly, total suspended solids (TSS) concentrations are usually less than 5 mg/L. The low concentrations of organic and inorganic turbidity result in very high water clarity in Stoneman Lake. Secchi disk measurements routinely exceed 2.5 m, and the recorded values usually represent obscuration of the disk by SAV or bottom sediments rather water column light attenuation.

Sedimentation Rate and Sediment Quality:
Estimated sedimentation rates in Stoneman Lake vary from about 0.03 cm/year over the last 1,360 years (Hasbargen, 1993) to 0.002-0.004 cm/year in the 1900s (McCabe, 1971). Percent-loss-on-ignition measurements indicate that the bottom sediments of Stoneman Lake are composed of 30 to 60-percent organic material in the upper 1 m (Hasbargen, 1993), presumably due to the high rates of plant production. In the 1990s ADEQ's Clean Lakes Program took sediment cores from Stoneman Lake and analyzed them for a variety of metals as well as water-leachable ammonia, Kjeldahl nitrogen, nitrate and phosphorus. These results are useful for estimating the nutrients that are available to SAV by way of root uptake.

1.3.2 Watershed Characteristics

The 900 acre natural watershed of Stoneman Lake consists mostly of pine and juniper forest covering hilly terrain. The only other significant land cover in the watershed is a residential development on the eastern side of the lake that contains approximately 70 homes (Figure 1-2). Most of these home are occupied seasonally and are served by septic systems. Geologically, the entire watershed is underlain by basaltic volcanic rocks that weather to clay loams of low-to-moderate permeability. Elevations in the Stoneman Lake watershed range from about 6,700 to 7,800 feet asl. Surface slopes vary between zero and 36 percent and are highest in the scarps that compose the "bowl" surrounding Stoneman Lake.

In the 1930s, the Civilian Conservation Corp (CCC) enlarged the Stoneman Lake watershed by about 330 acres through the construction of a diversion ditch on the western side of the lake (Figure 1-2). This ditch was temporarily closed to due flooding concerns during the winters of 1977-78, 1978-79 and 1979-1980, and was permanently closed in early 1982 by the placement of earthern/rock dams and breaching of the ditch wall.

Average annual precipitation rates in the Stoneman Lake watershed are approximately 24 inches and the average annual pan evaporation is about 56 inches (Gookin, 1981). However, precipitation rates exhibit much year-to-year variation. Most of the runoff from the watershed into the lake occurs during the early spring in response to snowmelt. There are numerous springs and seeps in the watershed, the flow from which sometimes reinfiltrates groundwater before reaching Stoneman Lake. Thus, there is no sharp distinction between surface runoff and groundwater flow to Stoneman Lake.

1.3.3 Anthropogenic History

Prehistory:
Human habitation in the area dates from 2000 years ago. Both the Sinaguan (cliff dwellers) and Hohokam (lived in pit houses) peoples occupied parts of the area in prehistory. The Sinaguan constructed Montezuma's Castle and ancestors of the Hopi Indians (Hohokam) are thought to have constructed Tuzigoot village near Clarkdale. More recently, various bands of the Apaches traveled through the area on periodic raids to the Verde Valley. Records indicate that Stoneman Lake has long been an important watering stop for travelers.

Last 500 years:
Ancestors of the modern Hopi Indians led Spanish explorer Antonio De Espejo to the area in 1583. (desertusa.com, Howard Shelton, 1999) Later, in the early 1800s, the lake was named Chavez Lake after Lieutenant Colonel Francisco Chavez of the New Mexico Volunteers.

In the late 1800s, the area was used as an important watering hole along a road from Albequerque to Prescott. The name "Stoneman Lake" was given by Prescott editor John Marion to honor General George Stoneman, who first came to Arizona as a young lieutenent with the Mormon Battallion in 1846. Stoneman was given command of the Military Department of California, of which Arizona was a part, in 1869.

Last Century:
Two hundred and forty acres of land was homesteaded on the east side of the lake in 1914 by Tom and Maria Drum. The property passed to Walter Durham in the 1920s, who converted some of the acreage to farmland and pasture and constructed a rudimentary ditch to import additional surface water from an adjacent watershed. Mr. Durham had seven cabins and a boat dock constructed near the lake. Remnants of these structures, as well as others built by P.J. Moran in the 1930s are still standing. The main complex located on the saddle above the lake burned around 1950. Additional cabins were built on the east side

of the lake and still stand today.

In 1948, the property was transferred to Dr. M.O. Dumas, a dentist from the Phoenix area. Dr. Dumas jointly owned and managed the property with Arthur Bunger, who married Dumas' daughter Martha. Up until 1960, the property was primarily agricultural. In 1960 the Bungers sold all but a five acre parcel to Westman Corporation for subdivision, but repurchased the acreage in 1964. Colder, Williams and White completed the subdivision into 136 parcels.

Twenty six acres plus five acres of dirt roads have been developed as single family residences. The development is known as "Ponderosa Paradise." Although Mr. Bunger originally intended all of the private property to be developed, the parcels fronting the lakeshore include approximately 60 acres on the lake bottom. These parcels have been recently purchased by three residents with the express purpose that the land remain undeveloped (Elliot, Hull & Williams). Currently, there are about 70 homes in the basin. All of these dwellings, with the possible exception of one or two, are seasonal homes, occupied only during the summer.

There is no electricity in the subdivision except for that supplied by generators. There are also no telephone lines or paved roads. The domestic water supply consists solely of spring water, collected from five springs and stored in large tanks. Wastewater disposal is primarily via septic tanks. There are a few older residences that have older systems (cisterns etc) and a couple of homes by the lake that have been fitted with alternative onsite disposal. Exact pumping records are unknown, but residents claim most of the systems have never been pumped (Focus Group, personal communication).

When the property was in agricultural use, the land was irrigated with an extensive sprinkler system that drew water from the lake. Martha Bunger reports that the lake has been known to go completely dry, e.g., in the summers of 1954 and 1964 (personal communication). The subdivision retains the native vegetation for the most part. Except for a few personal gardens there is no irrigated land, though the sprinkler system can still be seen on the Elliott property.

1.3.4 Other Land Uses and Management Issues

Forest Service:
Remaining land within the watershed is owned and managed by the U.S. Forest Service (FS). It has been decades since the basin and surrounding area were harvested for timber. In dry years the FS must conduct controlled burns in the area to reduce the risk of an extensive forest fire. The Happy Jack Ranger Station manages the area for day-use recreation; with the Game and Fish Department, they plan to enhance the boat launch this year. There is one cattle allotment, the "Apache Maid Allotment" that borders the Stoneman Lake basin. There have been reported incidents of cattle wandering into the basin occasionally when the fence becomes compromised (Rick Bunger; Dick Fleishman).

The supplemental ditch constructed by Walter Durham and later rebuilt by the Corps of Engineers Civilian Conservation Corp in the 1930s, is located on Forest Service land. The ditch supplies an additional 330 acres of runoff to the Stoneman Lake watershed. In 1979, the Regional Forester and the AZ Game and Fish Department acknowledged that “it is imperative to maintain all the flow in the ditch to offset climatic fluctuations and lake eutrophication” (Loyd Barnett for Michael Kerrick, 1979). This position was also supported by the U.S. Fish and Wildlife Service **(---).** However, the forest service position has been complicated by liability concerns regarding ditch maintenance, regulation and flooding of private property (Fleishman & Sears, personal communication).

In 1980, Mr. Bunger petitioned the forest service to install temporary diversion structures within the ditch; authorization was granted based on emergency flooding concerns. The temporary structures were removed in June 1980. Over the next year, several alternatives were discussed but resolution was not reached. By May of 1982, negotiations stalled and on June 4, 1982, the U.S. Forest Service Supervisor Paulson made a decision:

> 1) he would leave temporary diversion structures in the ditch for 365 days, 2) he offered an opportunity during the 365 days for some person or entity to apply for a special use permit to construct, operate and maintain a ditch regulating device and 3) if within 365 days no person or entity offered to construct, operate and maintain a regulating device, he [would] permanently render the ditch inoperable and incapable of delivering water to Stoneman Lake.

Six appeals were filed on Mr. Paulson’s decision, by Mr. & Mrs. Bunger, Mr. Dumas, Mr. Egar, the Coconino Sportsmen, the Stoneman Lake Homeowner’s Association and the Stoneman Lake Lake and Development Company (owned by Mr. Bunger). The basic issue, i.e., whether the U.S. Forest Service has the duty and authority to construct, operate and maintain a flow regulating device in the Stoneman Lake ditch, was the subject of oral presentations in the winter of 1983. The appellants concurred on the following points: 1) the ditch should be controlled when the lake level reaches 6726 ft, 2) the U.S. Forest Service should be held harmless of flood damages as long as the ditch was controlled according to plan and 3) FEMA must approve a formal operation and maintenance plan.
For purposes of the National Flood Insurance Program, FEMA adopted the elevation of 6729.6 in January of 1983.

The high water mark during the 1980 flood was 6730 ft, which encroached on several lakefront properties. Most lots at risk to flooding have been purchased by residents with the express purpose that they remain undeveloped (Elliott, Hull, Williams). Since the flooding issue has become less threatening to the community, there is a renewed interest to reopen and regulate the ditch. In order to do so would require resolution of the water right, agreement by a government entity to manage the flow, application for a special use permit, release of liability for the USFS and an environmental assessment under NEPA (Sears, personal communication).

USCOE:
U.S. Corps of Engineers staff visited the site and delineated the jurisdictional wetlands in 1990. It was determined that the "shoreline of the subdivision had been extensively altered by dredging and filling...the wetland boundary is above the current lake level, which was an elevation of 6727 in 1990." The lake is dry at 6717. Figure 1-3 shows the extensive dike structure that Mr. Bunger had designed by the SCS in 1954 to protect the agricultural land from flooding. At one time there may have been plans to fill the area behind the dike for additional developable land, however, no such extensive project was undertaken. Subsequent to the 1980 flood, Bunger raised the elevation of the southern portion of the Hull's property (parcel 51), the parcel most at risk of flooding. The 1990 delineation by USCOE states that any additional repair or alteration of the dike would require at minimum a nationwide 404 permit. Since the ditch was closed in 1982, the lake level has been slowly declining; by late 1999 it was down to approximately 6724 ft (maximum lake depth 2.1 m). Residents report that at the time of this writing (June 2000), the lake level has further declined to about 6722 ft.

AGFD:
The Arizona Game and Fish Department (AGFD) manages Stoneman Lake as a Northern Pike and White Perch fishery, species that were introduced in the mid 1960s. Prior to that time, AGFD reports the presence of yellow perch in the lake, which were introduced in 1919 (AGFD web site). Perch prefer clear water with moderate vegetation and feed on small fish, crawfish and insects. Pike thrive in areas congested with aquatic weeds, feeding on fish, frogs, crayfish, waterdogs, ducks, birds and mice. The water is cool enough to support these species year-round.

One area of cattails surrounding the lake, planted by Mr. Durham to attract waterfowl, has been periodically cut by AGFD (4-5 acres) in 1988, 1989, 1992, 1993 and 1994, to allow fishing and boating access (Dahlberg, 2000). The vegetation within the lake (submerged aquatic vegetation, or SAV) consists primarily of coontail, a floating submerged plant and milfoil, a rooted emergent plant. In 1999 the lake bottom was observed to be between 90-100 percent covered in vegetation. There are no records of SAV harvest by AGFD. One minor fish kill in the summer of 1995 was observed (ADEQ, AGFD).

USFWS:
The U.S. Fish and Wildlife Service (USFWS) issued a field report in 1979 stating the value of Stoneman Lake to fisheries and wildlife resources. This document recognizes that about 30 acres of wetlands lie behind the dike and lists species of animals and plants found in the basin. Of particular importance, the lake provides habitat and food for bald eagles. The USFS has indicated there are also additional 'sensitive species' such as the Mexican spotted owl, the Northern Goshawk and several species of butterflies present in the area. The Mexican spotted owl is the only one listed on the AGFD T&E list (Dahlberg, 2000).

2.0 DATA SUMMARY

This section of the report summarizes data available for the Stoneman Lake watershed. The purpose of this summary is to identify and describe geographic, hydrologic, water quality and other types of data that are potentially useful for assessing the controls on the water quality and living resources of Stoneman Lake. A comprehensive data summary is one of the first steps in the process to remove Stoneman Lake from the 303(d) list. The data described herein will be used to model the lake and watershed and evaluate alternatives for their management.

The datasets presented in this report were collected by a variety of agencies. If available, the following information is presented for each dataset:

- Source/collecting agency
- Time/date/period of collection
- Scale
- Format
- Methods of collection/verification
- Reliability and potential limitations

2.1 Watershed Characteristics

The category of watershed characteristics includes geographic data on the topography, soils and land cover of the Stoneman Lake watershed. Most of the datasets described in this section are available as geographic information system (GIS) coverages. The coverages themselves do not generally contain full descriptions of the geographic categories (e.g., soil types), but such descriptions are available in accompanying reports, metadata and documentation.

2.1.1 Topography

Elevation and Slope

Information on the topography of the Stoneman Lake watershed is available from two primary sources: (1) the USGS 7.5-minute topographic quadrangles and (2) USGS digital elevation model (DEM).

Topographic Quadrangles

The Stoneman Lake watershed is on the adjacent USGS 7.5-minute quadrangles entitled ‘Stoneman Lake’ and ‘Hutch Mountain’. These quadrangles are available in both hard-copy and as digital raster graphics (DRGs) from the USGS. The USGS topographic quadrangles have a scale of 1:24,000, a contour interval of 20 feet and were prepared by photogrammetric interpretation of aerial photographs taken in 1965. The maps have not been photorevised since their original publication. The elevation datum is the National Geodetic Vertical Datum of 1929. The DRGs are georeferenced to the Universal Transverse Mercator (UTM) system and are available from USGS (http://mcmcweb.er.usgs.gov/drg/) in Tagged Image File Format (TIFF).

In addition to the USGS, several private companies offer digital versions of topographic maps based on the USGS quadrangles. For example, DeLorme, Inc. offers bitmaps of topographic maps that include the Stoneman Lake watershed (Figure 2-1). These maps have a scale of 1:37,500 and use the datum of the World Geodetic System—1984 (WGS84). The contour interval of the DeLorme map is 50 feet.

Digital Elevation Models

A DEM is a digital array (raster format) of points with x, y and z coordinates, provided by the USGS as 7.5-minute quadrangles in the UTM coordinate system. DEMs are available for both the Stoneman Lake and Hutch Mountain quadrangles. Elevation data are stored in profiles at a 30 meter vertical interval and the DEMs use the North American Datum of 1927 (NAD27). The DEMs do not provide as much vertical resolution as the topographic maps described in section 2.1 and are not as useful as the maps for delineating watershed boundaries. However, the DEMs are useful for GIS analysis and graphical representation of elevation (Figure 2-2), flow direction and slope (Figure 2-3). Among other sources, DEMs are available from USEPA's BASINS web site (http://www.epa.gov/pst/basins).

FIGURE 2-1

FIGURE 2-2

FIGURE 2-3

2.1.2 Soils

There are three major sources of soil information for the Stoneman Lake watershed: (1) the soil survey of the Beaver Creek Area; (2) a digital statewide coverage of major soils units called AZSOIL; and (3) the State Soil Geographic Data Base (STATSGO). The Soil Survey Geographic (SSURGO) database does not cover the Stoneman Lake watershed. The U.S. Forest Service terrestrial ecosystem survey includes information on soils and is described in section 2.1.6.

SCS Soil Survey of the Beaver Creek Area
This soil survey was produced in 1966 by the Soil Conservation Service (SCS) (now called the Natural Resources Conservation Service or NRCS), U.S. Forest Service and the University of Arizona Agricultural Experiment Station. The survey has not been digitized and thus is currently available in hardcopy format only. The survey classifies soils in the Stoneman Lake watershed as belonging to one of three units: the Friana, Brolliar and Sieta-Sponsellar series. The SCS soil survey provides more detail on the Stoneman Lake watershed than the other two soil data sources described below.

AZSOIL
AZSOIL is a digital (vector and polygon) version of the General Soil Map—1975 of Arizona that was produced by the SCS and the University of Arizona Agricultural Experiment Station. It is in UTM coordinates, with a scale of 1:1,000,000. Due to the relatively small scale, it has a lower resolution than the SCS soil survey described in section 2.1.2 and uses a different soil classification theme. In this coverage the entire Stoneman Lake watershed is classified as belonging to the Sponseller-Ess-Gordo association of gravelly and cobbly loams. The three components of this association occur on different slopes and greater resolution of soil types can be achieved by combining the AZSOIL coverage with the DEM-derived slope coverage. AZSOIL is available from the Arizona Land Resource Information System (ALRIS; http://www.land.state.az.us/alris/alrishome.html).

STATSGO
The NRCS created the State Soil Geographic Database (STATSGO) in 1991 by compiling information from more detail soil surveys. STATSGO data for Arizona are available as a 1:250,000 scale GIS coverage in UTM coordinates. As with AZSOIL, the entire Stoneman Lake watershed falls within a single large map unit, designated as Derecho-Mirand. Due to the lack of resolution relative to the small size of the Stoneman Lake watershed, the STATSGO data are of limited use for watershed characterization. STATSGO data are downloadable from the NRCS STATSGO website (http://www.ncg.nrcs.usda.gov/stat_data.html) as well as from the USEPA BASINS web site (http://www.epa.gov/pst/basins).

2.1.3 Geology

Two low-resolution geologic maps are available that include the Stoneman Lake watershed: (1) the statewide Geologic Map of Arizona; and (2) a USGS report entitled Generalized Geology in the Upper Verde River Area. Both are available as GIS coverages in UTM coordinates, the former from ALRIS (http://www.land.state.az.us/alris/htmls/data2.html) and the latter from the Verde River Watershed web page (http://www.verde.org). The statewide map has a scale of 1:1,000,000 and characterizes the entire Stoneman Lake watershed as basaltic rocks (Pliocene to late Miocene; 4 to 8 Ma.). The Upper Verde River area map has a scale of 1:250,000 and characterizes the entire Stoneman Lake watershed as volcanic and sedimentary rocks. Obviously, neither map provides resolution of geologic variations within the watershed. The best sources of site-specific geologic information comes from two master's theses performed on the Stoneman Lake area:

Geology and Botany of the Stoneman Lake Area by Kirk W. McCabe (1971): Northern Arizona University

Origin of Stoneman Lake and Volcano-Tectonic Relations of Mormon and San Francisco Volcanic Fields by James M. Dohm (1995): University of Utah

Both documents include geologic maps and cross-sections of the Stoneman Lake area and descriptions of petrologic variations, structure and other geologic features. The Dohm thesis includes mapping of faults and lineaments that could influence the direction of regional groundwater flow. With respect to hydrologic/water quality modeling of Stoneman Lake, the most important information to be gleaned from these sources of geologic data is that the entire shallow subsurface consists of fractured basalts. The Kaibab limestone underlies the lake at depth (<100 feet) but is not expected to influence present-day lake chemistry.

2.1.4 Land and Land Use Cover

Land use/cover data for the Stoneman Lake watershed are available in the form Geographic Information Retrieval Analysis System (GIRAS) coverages that were originally produced by the USGS in the 1970s and early 1980s and were converted to ARC/INFO format by the USEPA in 1994. The 1:250,000 scale coverages were created by interpretation of aerial photographs taken in the 1970s and are in UTM coordinates. Land use/cover are mapped and coded according to the Anderson Level II classification system, with a minimum map unit size of 40-acres for non-urban land uses. GIRAS land use data are downloadable from the USEPA BASINS web site (http://www.epa.gov/pst/basins). According to GIRAS data, the Stoneman Lake watershed entirely of 'evergreen forest land' except for a small parcel of 'residential' land on the east side of the lake (Figure 2-4). Although the classification is based on 1970s era aerial photography, the only change that is likely to have taken place since then is a slight enlargement of the residential area.

FIGURE 2-4

2.1.5 Vegetation Cover

Two GIS coverages of *natural* vegetative cover are available as described below, both based on classification schemes of David E. Brown and Charles H Lowe. A third coverage of *actual* vegetative cover in Arizona was developed by the National Biological Survey based on 1990-1992 LANDSAT Thematic Mapper imagery. However, this dataset is not currently available because it is being revised due to known errors.

GFVEG

A coverage entitled GFVEG depicts natural vegetative boundaries as shown in the Journal of the Arizona Academy of Science, volume 9, supplement 2, appendix F, published in May 1974. Wildlife managers of the Arizona Game and Fish Department (AGFD) drew the original 1:126,720 scale map based on a classification scheme of Brown and Lowe and the University of Arizona digitized the map in 1992 and 1993 into UTM coordinates. This coverages classifies most of the Stoneman Lake watershed as 'pine communities', with a small portion of the watershed in the west classified as ponderosa pine and juniper association (Figure 2-5). Interestingly, Stoneman Lake itself is classified as a freshwater marsh. GFVEG data for the Stoneman Lake watershed are available from ALRIS (http://www.land.state.az.us/alris/alrishome.html) as well as from the Verde River Watershed web site (http://www.verde.org), where it is called VGFVEG.

NATVEG

Of lesser resolution than GFVEG is NATVEG, which was digitized from a 1:1,000,000 scale map in *Biotic Communities of the Southwest* (Brown and Lowe, 1980) and is in UTM coordinates. NATVEG uses a different classification scheme than GFVEG; the entire Stoneman Lake watershed falls within a large map unit called 'Petran Montane conifer forest'. NATVEG is available from ALRIS.

2.1.6 Terrestrial Ecosystem Survey

One of the most useful sources of geographic data in the Stoneman Lake watershed is a terrestrial ecosystem of survey of the Coconino National Forest published by the U.S. Forest Service in 1995. Forest mangers performed the survey by stereographic interpretation of 1:24,000 aerial photographs and field verification during period 1987 to 1991. As a result, 134 different ecosystems were identified primarily based on combinations of soil type, landform and vegetative community. For each ecosystem mapped, the accompanying documentation describes the soil type (family level), major landform features and potential plant communities. Information is also provided on erodibility, slope, soil permeability and use limitations. The terrestrial ecosystem maps are available from the U.S. Forest Service as a GIS coverage in UTM coordinates. Nine different types of ecosystem map units were identified within the natural and 'ditch' watersheds of Stoneman Lake (Figure 2-6). The ecosystem survey provides higher resolution and better characterization of the watershed than any other soil or land use coverage. For this reason, it would be the most useful data source for estimating hydrologic characteristics of the land surface (e.g., runoff coefficients, infiltration rates, etc.).

FIGURE 2-5

FIGURE 2-6

2.1.7 Roads and Buildings

Road networks in the Stoneman Lake area are depicted both on USGS quadrangles and a GIS coverage provided by ADEQ. The only buildings in the Stoneman Lake watershed are the houses and associated outbuildings of the Ponderosa Paradise property on the east side of the lake. This property contains a total of 136 developable lots according to plans prepared in 1964. The number of buildings has been steadily increasing since the 1960s as the lots are developed. Although several aerial photographs are available, they are of insufficient resolution to precisely identify the number and location of all houses. The 1965 USGS topographic quadrangle shows a total of 21 buildings in the division. A 1975 map of the proposed water system shows a total of 43 lots requiring water. It is now estimated by homeowners that there are about 70 homes in the division. Malcolm Pirnie is currently attempting to contact the Coconino County Department of Environmental Health to determine the number and type of permitted wastewater disposal systems.

2.2 Hydrography and Hydrology

2.2.1 Watershed Boundaries

The boundaries of the natural and CCC ditch watersheds of Stoneman Lake have previously been delineated both by the U.S. Forest Service and a private consultant in the early 1980s. The Forest Service delineated the watersheds in 1980 as part of a study called the Environmental Assessment: Stoneman Lake Ditch Regulation (Howard, 1981). These watershed boundaries are available from the Forest Service as a GIS coverage in UTM coordinates. W.S. Gookin and Associates (1981) performed an independent delineation of the watershed boundaries as part of hydrologic study performed for Mr. Bunger. The ditch watershed was delineated again in April 2000 by Malcolm Pirnie using GPS measurements of the ditch location taken by the Arizona Department of Environmental Quality (ADEQ) and Malcolm Pirnie. The watershed boundaries shown in Figure 2-6 are based on the Forest Service delineation of the natural watershed and Malcolm Pirnie's delineation of the ditch watershed.

2.2.2 Springs, Streams and Ditches

Groundwater discharges from the steep bluffs surrounding Stoneman Lake in the form of springs and seeps. Five major springs in the watershed have been identified by ADEQ, all on the eastern slope (Figure 2-7). One of the springs, known as Tom's Drum Spring, serves as a source of drinking water to the Ponderosa Paradise community. Sources of stream hydrography for the study area include the USGS topographic quadrangle, USGS DLGs and the USEPA Reach File 3. None of these data sources show any streams within the Stoneman Creek watershed. During the Malcolm Pirnie/ADEQ site visit performed in April 2000, it was noted that discharge from at least one spring reaches the lake via a surface channel. Discharge from other springs probably reaches the lake via surface drainage during wet periods of the year, when the soil is saturated. However, surface flow within the watershed occurs mainly in response to precipitation events and snowmelt. The CCC ditch, was constructed in the 1930s to divert additional surface drainage into Stoneman Lake (Figure 2-8).

FIGURE 2-7

FIGURE 2-8

2.2.3 Lake Level, Depth and Area

There has been no regular gaging of the level of Stoneman Lake. The lake used to have a staff gage, but it is unknown if it still exists. The best source of information on how the lake level has varied with time is estimates performed by the U.S. Forest Service as part of the Environmental Assessment: Stoneman Lake Ditch Regulation (Howard, 1981) whereby 26 estimates of lake level over the period 1896-1980 were obtained from the following sources:

- Aerial photographs
- Ground-based photographs
- Elevation surveys
- Staff gage measurements
- Depth reports from AGFD
- Personal communications with Mr. Art Bunger

Additional estimates of lake level can be made using aerial photographs taken since 1980, depth estimates taken during water quality sampling events and a bathymetric survey performed by ADEQ in late March to early April 1999 (Figure 2-9). In conjunction with topographic data (see section 2.1.1), the results of the 1999 bathymetric survey can be used to estimate the lake depth and volume at other lake levels. It should be noted that the bathymetric survey did not cover the portions of the lake to the east of the dike and thus little information is available concerning the depth of these impounded areas. Lake surface area may be measured directly from aerial photographs for certain years and may also be estimated using a combination of lake level and topographic information.

2.2.4 Meteorological Data

Daily precipitation and air temperature data are available from a large network of NOAA cooperative weather stations in central Arizona and are downloadable from the Utah Climate Center (http://climate.usu.edu/). The stations closest to Stoneman Lake are listed in Table 2-1. The meteorological station at the Happy Jack Ranger Station is the closest in to Stoneman Lake and also is the most similar in elevation to the Stoneman Lake watershed. Therefore, this station is the most useful for hydrologic analysis of the watershed. The Flagstaff airport gage is the next closest in elevation and will be useful for estimating temperature and precipitation prior to the installation of the Happy Jack station in 1969.

TABLE 2-1
METEOROLOGICAL STATIONS NEAR STONEMAN LAKE

NOAA Cooperative Station Number	Station Name	Period of Data Availability
040402382802	Happy Jack Ranger Station	May 1969-Dec 1998
040402301002	Flagstaff Airport	Jan 1950-Dec 1998
040402563503	Montezuma Castle	Oct 1938-Dec 1998
040402770802	Sedona	Jul 1948-Dec 1998
040402067003	Beaver Creek Ranger Station	Feb 1957-Dec 1998
040402087102	Blue Ridge Ranger Station	Jul 1967-Dec 1998
040402570802	Mormon Lake	Jul 1948-Dec1998

Additional precipitation data were collected as part of the Beaver Creek Evaluation Project conducted by the US Forest Service. This series of silvicultural-environmental studies included a network of about 60 precipitation gages at which data were collected between 1957 and 1982 (Figure 2-10). Monthly and/or annual precipitation data are available for these gages from the Beaver Creek Evaluation Project web site (http://www.rmrs.nau.edu/wsmgt/beavercr/). Precipitation data were collected using recording rain gages, standard 8-inch rain gages located next to recording gages, isolated standard 8-inch rain gages and Sacramento storage gages that were read only twice per year. These data have not necessarily been reviewed for quality by the collecting scientists.

2.2.5 Runoff/Streamflow

As mentioned in section 2.2.2 there are no major streams within the Stoneman Lake watershed and thus no streamflow data. When the CCC ditch was open, no stream discharge measurements were taken. However, streamflow data are available from almost 40 stream gages in the nearby Beaver Creek watershed (Figure 2-11) as part of the Beaver Creek Evaluation Project. Streams were gaged using trapezoidal flumes and strip-chart level recorders. All data are downloadable from the Beaver Creek Evaluation Project web site (http://www.rmrs.nau.edu/wsmgt/beavercr/). As with the rainfall data, the streamflow data have not necessarily been reviewed by the collecting scientists.

Of most relevance to the Stoneman Lake watershed are data collected from watersheds 8 and 13 (Figure 2-11), which have similar characteristics. Watershed 13 was used as a 'control' watershed for studies of the hydrologic effects of different silvicultural practices and thus this watershed received no treatments. Daily streamflow data are available from the Beaver Creek web site for 1959 through 1983 and from the USGS between 1983 and 1996. Watershed 8 received no treatment until 1974, when it was lightly thinned. Daily

streamflow data are available for this station for the period 1960 to 1983.
Figure 2-9

FIGURE 2-10

FIGURE 2-11

2.3 Water and Sediment Quality

A variety of agencies have collected water quality data in or near the Stoneman Lake watershed, including the sampling of precipitation, springs, streams and the lake itself. This section summarizes the availability of chemical data that are potentially useful for assessing or modeling Stoneman Lake.

2.3.1 Precipitation

The only local source of precipitation quality data is the Beaver Creek Evaluation Project of the U.S. Forest Service, which involved periodic monitoring for conductivity, calcium, magnesium, potassium, sodium, ammonium, nitrate, orthophosphate and total phosphorus. More than 600 samples were analyzed between 1977 to 1980 and the data are downloadable from the Beaver Creek Evaluation Project web site (http://www.rmrs.nau.edu/wsmgt/beavercr/). Precipitation samples were collected in standard rain gages. These data have not necessarily been reviewed for quality. However, the data set as a whole will provide useful information on seasonal variation in precipitation nutrient concentrations.

2.3.2 Streams and Springs

As with streamflow data, no stream quality data are available from the Stoneman Lake watershed and the best source of background surface water quality data is the Beaver Creek Evaluation Project. Periodic grab samples were collected from most stream gaging locations by immersing the collection container in the center of the streamflow. More than 80 samples were collected from both Watershed 8 and Watershed 13 between 1974 and 1980. Analytes include conductivity, calcium, magnesium, potassium, sodium, ammonium, nitrate, orthophosphate and total phosphorus. As with all data downloadable from the project web site, it has not necessarily been reviewed for quality. However, it will be useful for examining seasonal variations in runoff quality. In addition, samples collected during baseflow periods provide information on the quality of shallow groundwater.

ADEQ sampled five springs on the eastern side of the Stoneman Lake watershed on October 14, 1999 (Figure 2-7). One grab sample was collected from each spring and analyzed for the following parameters*: alkalinity, total suspended solids, total dissolved solids, sulfate, pH, calcium carbonate, fluoride, specific conductance, chloride, turbidity, bicarbonate, carbonate, ammonia nitrogen, kjeldahl nitrogen, nitrate plus nitrate nitrogen, phosphorus. No other groundwater quality data are known to exist for the Stoneman Lake watershed. *total (i.e., unfiltered) unless otherwise noted

2.3.3 Stoneman Lake Water Quality

There are at least three documented sources of water quality data for Stoneman Lake: (1) sampling performed under the ADEQ Clean Lakes Program during 1995-99, (2) sampling performed by AGFD and ADEQ during 1985-87 and (3) periodic field measurements by AGFD. The Coconino County Department of Environmental

Health may have also performed some recent sampling. However, this has not yet been confirmed. The three documented data sets are described further below:

Clean Lakes Program

ADEQ sampled Stoneman Lake on nine different dates during the period 1995-1999. Table 2-2 shows the results of these nine events by date and by crucial parameter. Other data on metals and inorganics are available upon request. Sediment samples were also collected and analyzed for leachable nutrients. Prior to 1999, all samples were collected at station A (Figure 2-7). In 1999, samples were collected also collected at station B. On October 14, two additional samples were collected from two stations along the dike, but not from A and B.

Table 2-2: Clean Lakes Sample Data

Lake Site	Date	Time	Depth (m)	Temp	pH	DO% sat	DO mg/L	Chlor-a ug/L	Secchi Depth	Comments
A	8/14/95	11:35a	0.1	23.52	**9.93**	**47.9**	**3.09**			***FISH KILL (partly cloudy)**
			0.5	22.39	**9.84**	**20.5**	**1.27**			
			1.0	20.21	**9.59**	**3.0**	**0.30**	<2		Total N=1.35 mg/L Total P=0.019 mg/L Lab pH = 9.4 Hardness=85 EC/TDS: 290/210
			1.5	20.23	**9.08**	*1.1*	*0.13*			
			2.0	18.29	6.91	*0.9*	*0.60*			
			2.5	15.74	6.66	*0.7*	*0.06*			Lab pH = 6.6 Hardness=360 EC/TDS: 742/500
			3.0	14.06	**6.45**	*2.2*	*0.13*		*	weeds?
			3.2	14.15	**6.42**	*4.8*	*0.42*			
A	11/13/96	8:55a	0.1	6.10	9.**06**	110.9	11.06			100% macrophyte cover
			0.5	6.08	9.**07**	111.7	11.06			
			1.0	6.08	9.**08**	113.1	11.23	<2		Total N=0.64 Total P=0.029 Lab pH=9.06 Hardness=181 EC/TDS: 579/384
			1.5	6.12	9.**08**	107.6	10.99		>*	Top of weeds
			---	---	---	---	---			Bottom?

Lake Site	**Date**	**Time**	**Depth (m)**	**Temp**	**pH**	**DO% sat**	**DO mg/L**	**Clor-a ug/L**	**Secchi Depth**	**Comments**
A	2/20/97	2:15p	0.1	6.40	8.63	105.6	10.50			70-80% full?
			0.7	6.38	8.66	104.2	10.30			
			1.0	6.38	8.67	103.7	10.25	<2		Total N=0.72 Total P=0.048 Lab pH=8.70 Hardness=174 EC/TDS: 536/357
			1.5	6.40	8.70	106.2	10.42			
			1.7	6.41	8.70	106.9	10.59		>*	Top of weeds
A	6/30/97	12:00p	0.1	21	**9.51**	147.7	10.6			70-80% full?
			0.6	21	**9.52**	149.6	10.75			Total N=1.57 Total P=0.109 Lab pH=9.4 Hardness=220 EC/TDS: 700/450
			1	20.92	**9.52**	113.3	10.31	**22.5**		Plant material in sample??
			1.2						>*	Top of weeds Total N=1.50 Total P=0.113 Lab pH=9.3 Hardness=240 EC/TDS: 690/460
			1.8	18.06	6.87	*6*	*0.45*			
A	8/13/97	11:43a	0.1	24.17	**9.68**	165.2	11.49			Lake level very low
			0.3	24.16	**9.69**	159.4	11.09	3.84		Total N=1.31 Total P=0.101 Lab pH=9.7 Hardness=193 EC/TDS: 670/450
Lake Site	**Date**	**Time**	**Depth (m)**	**Temp**	**pH**	**DO% sat**	**DO mg/L**	**Clor-a ug/L**	**Secchi Depth**	**Comments**

A	8/13/97 cont.		0.4	23.66	**9.68**	139.8	9.79			
			0.5						>*	
			0.7	22.17	**9.64**	120.8	8.72			
			1.1	22.78	**9.65**	107.2	7.66			max depth
A	3/18/99	1:20p	0.1	9.37	8.24	91.6	8.23			
			0.5	9.38	8.78	90.4	8.09	<2		Total N=1.60 Total P=0.079 Lab pH=8.6+ Hardness=200 EC/TDS: 610/410
			1	9.35	8.78	89.9	8.1			
			1.5	9.38	8.79	93.3	8.36		>*	Top of weeds Total N=1.57 Total P=0.101 Lab pH=8.6+ Hardness=210 EC/TDS: 610/410
			1.9	9.37	8.8	92.3	8.38			max depth 2.0m
B	3/18/99	2:45p	0.1	9.87	8.88	97.1	8.6			
			0.5	9.86	8.81	96.5	8.56			
			1	9.85	8.82	97.7	8.66	<7		Total N=1.72 Total P=0.058 Lab pH=8.6+ Hardness=220 EC/TDS: 610/410
Lake Site	Date	Time	Depth (m)	Temp	pH	DO% sat	DO mg/L	Clor-a *u*g/L	Secchi Depth	Comments

B	3/18/99 cont.		1.5	9.77	8.83	92	8.32		*	prolific weeds max depth
A	5/19/99	9:55a	0.1	17.26	8.93	100.9	7.6	<2		Total N=0.89 Total P=0.095 Lab pH=9+ Hardness=230 EC/TDS: 710/430
			0.5	17.29	8.92	100	7.51			
			1	17.29	8.93	101.5	7.55			~same as 0.1m chemistry
A			1.5	17.13	8.94	86.4	7.9		>*	Top of weeds @ 1.4 m
B		10:55a	0.1	18.18	8.93	122.3	8.87			Total P=0.11; otherwise same as site A
			0.5	----	8.98	123.3	9.12			
			1	18.18	8.99	125.7	9.34		>*	~same as 0.1m chemistry
			1.5	18.2	9.02	108	10.35			Top of weeds @ 1.4 m; max depth 1.6 m
A	8/18/99	11:10a	0.1	21.58	**9.98**	168	11.73			Thunderstorm interupted sampling
			0.5	21.48	**9.99**	178.2	12.54			
			1	20.88	**10.02**	136.7	8.99			
			1.5	18.79	8.58	*6.4*	*0.55*			max depth 2.0 m
	8/19/99	1:30p	0.1	22.24	**9.84**	99.2	6.96			
			0.5	20.96	**9.9**	158.9	10.97			
			1	19.11	**9.89**	105.9	7.45	<4	>*	Total N=0.61 Total P=0.190 Lab pH=10+ Hardness=170 EC/TDS: 660/450
			1.5	18.48	**9.66**	*10*	*0.74*			
			2	18.18	8.72	*2.3*	*0.18*			max depth
Lake Site	**Date**	**Time**	**Depth (m)**	**Temp**	**pH**	**DO% sat**	**DO mg/L**	**Clor-a ug/L**	**Secchi Depth**	**Comments**

B	8/19/99	2:20p	0.1	22.65	**9.89**	138.6	9.47			Chlor-a not collected
			0.5	22.55	**9.9**	153.7	10.51			
			0.75						>*	Total N=0.64 Total P=0.160 Lab pH=10+ Hardness=200 EC/TDS: 670/460
			1	20.47	**9.89**	*65.6*	*4.61*			
			1.5	19.07	**9.15**	*5.2*	*0.41*			max depth 1.7 m
A	10/13/99	11:00a	0.1	16.69	**9.55**	160	13.1			water level low-med
			0.5	16.57	**9.57**	160	13.13			
			1	16.31	**9.57**	168	13.9	<2	>*	Total N=0.52 Total P=0.130 Lab pH=9.6+ Hardness=190 EC/TDS: 680/450
			1.5	16.32	**9.58**	165.9	13.82			
			1.7	15.98	**9.52**	135	10.71			max depth
B		12:05p	0.1	17.05	**9.42**	**83.4**	**6.76**			
			0.5	17.02	**9.45**	**82.8**	**6.73**			
			0.75					<3		Total N=0.56 Total P=0.110 Lab pH=9.4+ Hardness=190 EC/TDS: 690/450
			1	16.81	**9.43**	**82.1**	**6.67**		>*	
			1.4	16.35	**9.42**	*43.5*	*3.8*			max depth ~ 1.5 m

When sampling the lake, ADEQ personnel would first measure the vertical profile of field parameters (pH, D.O., specific conductance, total dissolved solids, temperature, turbidity and redox potential) in the water column using a Hydrolab®. Sampling depths were chosen based on field parameter results and samples were collected at those depths using a beta bottle. Samples were preserved, chilled immediately and analyzed either at the State

Laboratory or at Aquatic Testing Consultants, Inc.

These data are available from ADEQ in electronic and hardcopy format. Results available include all laboratory and field measurements, including secchi depth and lake depth. Secchi depth and turbidity measurements were strongly influenced by interference from macrophytes and thus these measurements should not be used to directly estimate light extinction coefficients. In addition, the laboratory pH measurements are not necessarily indicative of field conditions. The Clean Lakes Program adheres to quality assurance (QA) protocols including decontamination of equipment and collection of 10 percent QA samples, including duplicate samples. Due to number of samples and large number of constituents analyzed, this dataset is the singlemost useful single source of information on the quality of Stoneman Lake

ADHS/ADEQ/AGFD

Samples were collected from Stoneman Lake by the Arizona Department of Health Services (ADHS) and Arizona Game and Fish Department ADEQ on the following dates:

1985	July16
	October 23
1986	April 28
	July 22
	November 24
1987	August 18
	December 3

Field measurements included lake depth, secchi depth, pH, temperature, conductivity and dissolved oxygen. The August 13 and December 3, 1987 sampling events included vertical and horizontal profiling of field parameters and sampling at multiple locations

Data are available from ADEQ in hardcopy format. This dataset is smaller and not as well-documented as the Clean Lakes Program dataset. For example, the sampling locations, depths and times are not all precisely known. Sampling depths are listed as ‘0.0’, suggesting that they were collected from the surface. However, these data are useful for comparing 1980s lake conditions with 1990s conditions.

AGFD Field Measurements

Since the 1950s AFGD has periodically measured field parameters in Stoneman Lake, including secchi depth, water temperature, alkalinity, pH and dissolved oxygen. AGFD has provided hard copies of data sheets that record measurements on over 80 dates between 1959 and 1976. However, not all parameters were recorded on every date. Some records between 1968 and 1970 also include estimates of zooplankton and phytoplankton concentrations. Although sampling locations, depth and methods are not documented, these data are useful for examining seasonal and annual changes in pH; out of 43 measurements, 16 (37 percent) were above 9.0 and of the 16 high measurements, 11 (69 percent) occurred between May and September.

2.3.4 Stoneman Lake Sediments

The Clean Lakes Program of ADEQ took 2.5-inch diameter sediment cores of Stoneman Lake on the following dates:

June 30, 1997
March 18, 1999
May 19, 1999
October 13, 1999

The core samples were analyzed for a variety of metals as well as water-leachable ammonia, Kjeldahl nitrogen, nitrate and phosphorus. These data are useful for estimating the amount of nutrients available to macrophytes in the sediments of Stoneman Lake and the amount of nutrients that could be released to the water column. The sediment quality data are available from ADEQ in hardcopy and electronic format.

Other information on the characteristics of the lake sediments is available from the McCabe thesis (see section 2.3) and another NAU master's thesis entitled *The Paleoenvironment of Stoneman Lake, Arizona* by Jim Hasbargen (1993). Both of these studies involved radiocarbon dating and analysis of sediment, pollen and diatoms in cores from Stoneman Lake and both provide interpretations of changes in climate, vegetative community and sedimentation rate over time. The Hasbargen thesis includes an estimate of the geologically recent sedimentation rate (about 0.03 cm/year over the last 1,360 years) and percent-loss-on-ignition measures that can be used to determine the organic content of sediments in the upper 200 cm of Stoneman Lake. The McCabe thesis provides an estimate of the historically recent sedimentation rate (0.002-0.004 cm/year in the 1900s).

2.3.5 Stoneman Lake Macrophytes

An AGFD survey performed on November 30, 1979 identified Eurasian milfoil (*Myriophyllum spicatum*) as the dominant submerged species in the diked areas and suggested the presence of coontail (*Ceratophyllum demersum*) and pondweed (*Potamogeton* sp.). ADEQ cites milfoil and coontail as the dominant species observed in Stoneman Lake in 1999 (S. Fitch, pers. commun) and these genera were noted during the Malcolm Pirnie/ADEQ site visit in April 2000.

Interestingly, Jim Hasbargen's Master's thesis (1993) states that pondweed and milfoil pollen "increased in abundance" about 1,500 years ago, showing that the presence of submerged macrophytes in Stoneman Lake has not been restricted to recent decades. Similarly, a 1934 biological survey of the lake by the Bureau of Fisheries noted abundant vegetation in the lake. There is little information on the mass or density of submerged macrophytes beyond observations that almost 100-percent of the lake bottom supports macrophytes during the summer.

2.4 Conceptual Model

The water quality and macrophyte problems of Stoneman Lake are typical of many clear, shallow lakes. Even without high external loads of nutrients, the shallowness, clarity and lack of hydraulic flushing all favor high rates of primary production, which in turn cause large daily and seasonal swings in dissolved oxygen (D.O.) and pH. D.O. is consumed both by plant respiration and the decay of plant material. The D.O. stratification that has been observed during the summer is likely to be caused by the SAV canopy that impairs vertical mixing and reaeration of water below the canopy.

Although pH is generally higher in the summer, it remains at least eight and a half even during the winter when primary production is very low. This suggests that pH is naturally high in Stoneman Lake due to the presence of alkaline rocks (basalts) and soils. Even low rates of photosynthesis may be sufficient to raise pH above the upper criterion. The low rates of algal production are probably caused by the dominance of macrophytes in competition for nutrients and light. TSS concentrations are low in the lake due to low erosion rates in the forested watershed and trapping of sediment in the bullrush fringe and impoundments.

Hydrologic and nutrient inputs to Stoneman Lake include direct precipitation, runoff and groundwater discharge. Wastewater loads to groundwater are the only significant anthropogenic source of nutrients (nitrogen) to the lake. Runoff rates in the Stoneman Lake watershed are expected to be higher than that in adjoining watersheds due to the greater slopes of the escarpments surrounding the lake. In addition to external inputs, nutrient recycling within the lake is expected to be a major source of nutrients to macrophytes and to the water column. Nutrient release rates are expected to be high due to decay of plants and organic material in the sediments.

The major sinks of nitrogen are probably denitrification in the sediments, volatilization of ammonia and recharge to groundwater. The importance of groundwater recharge to the hydrologic and chemical balance of the lake is illustrated by the moderate total dissolved solids concentrations (200-600 mg/L), as first pointed out by Gookin (1981). In other words, if there were no mechanism for transporting dissolved ions out of the lake, it would be expected to have become saline over geologic time. The major sink of phosphorus is probably burial/inactivation in the lake sediments.

2.4.1 Data availability

In general, there are sufficient geographic, hydrologic and water quality data to develop and calibrate a hydrologic/water quality model of Stoneman Lake and its watershed. The most valuable data are derived from ADEQ (lake water quality and bathymetry) and the U.S. Forest Service (terrestrial ecosystem survey and hydrologic/water quality data from the Beaver Creek Evaluation Project). Given the short time frame for TMDL model development, it is impractical to collect additional data specifically for the TMDL model.

The water quality and macrophyte problems of Stoneman Lake are typical of many clear, shallow lakes.

Although the watershed is relatively pristine, the shallowness, clarity and lack of hydraulic flushing all favor high rates of primary production, which in turn cause large daily and seasonal swings in dissolved oxygen (D.O.) and pH. It is expected that recycling within the lake is a major source of nutrients to macrophytes and the water column.

Pollen analysis of cores shows that milfoil and pondweed have grown in the lake for centuries (Hasbargen, 1993) and abundant vegetation has been noted in the lake at least since the 1930s and probably earlier. Therefore, the present state of the lake might be a natural condition. However, it is unclear if wastewater loads have exacerbated the problem, or if lake/watershed management techniques can significantly improve the lake as a wildlife habitat and recreational resource.

2.4.2 Patterns in Water Quality

Examination of water quality data collected by ADEQ and other agencies during the 1980s and 1990s reveals seasonal patterns in both D.O. and pH. The D.O. problems appear to be restricted to summer, when a marked D.O. stratification occurs in the lake. The lake is unstratified during other seasons. There is no statistical correlation between D.O. concentration and antecedent rainfall, water temperature, or sampling time of the seven summer sampling events since 1985. However, it may be reasonably predicted that D.O. is higher when the lake level is higher and that rain events will at least temporarily increase D.O. concentrations.

Although pH is generally higher in the summer, it remains at least eight and a half even during the winter when primary production is very low. This suggests that pH is naturally high in Stoneman Lake due to the presence of alkaline rocks (basalts) and soils. Even low rates of photosynthesis may be sufficient to raise pH above the upper criterion.

2.4.3 Primary Production

With the exception of one measurement in June 1997, chlorophyll a concentrations are consistently less than 5 µg/L even during the summer. In combination with the lack of observed algal blooms, this demonstrates relatively low phytoplankton production, probably caused by the dominance of macrophytes in competition for nutrients. N/P ratios indicate a marginally phosphorus-limited system most of the year. The lack of algae and low concentrations of total suspended solids result in excellent water clarity, such that no water column or leaf-surface light limitations on macrophyte growth are expected under typical summer lake levels.

Little information exists on the seasonal and hydrologic variations of macrophyte growth in the lake. U.S. Forest Service personnel observed that macrophyte growth in the lake was below normal in 1980, when lake levels were very high. Assuming that the macrophytes need approximately 10-percent of the surface light to survive and that the minimum secchi depth is 10 feet, the lake would have to be about five meters deep to induce a light limitation on macrophytes. This is about twice the maximum depth measured in October 1999.

2.4.4 Hydrologic and Nutrient Budget

Hydrologic and nutrient inputs to Stoneman Lake include direct precipitation, runoff and groundwater discharge. Wastewater loads to groundwater are the only significant anthropogenic source of nutrients (nitrogen) to the lake. Runoff rates in the Stoneman Lake watershed are expected to be higher than that in adjoining watersheds due to the greater slopes of the escarpments surrounding the lake.

The diked impoundments on the east side of the lake will act in the manner of stormwater detention/infiltration basins. During periods of low lake level, the water level in the impoundments is higher than that of the lake itself and groundwater will seep through the dikes into the lake. The impoundments will effectively delay the flow of runoff and groundwater discharge to the lake and also trap sediment and particulate nutrients from the developed area.

In addition to external inputs, nutrient recycling within the lake is expected to be a major source of nutrients to macrophytes and to the water column. The upper 60 cm of sediments contain 30-60-percent organic material by dry mass (Hasbargen, 1993). Nutrient release rates are expected to be high both from decay of organic material in the sediments and plants.

The major sinks of nitrogen are probably denitrification in the sediments, volatilization of ammonia and recharge to groundwater. The importance of groundwater recharge to the hydrologic and chemical balance of the lake is illustrated by the moderate total dissolved solids concentrations (200-600 mg/L), as first pointed out by Gookin (1981). In other words, if there were no mechanism for transporting dissolved ions out of the lake, it would be expected to have become saline over geologic time. The major sink of phosphorus is probably burial/inactivation in the lake sediments.

2.5 Recommendations for Quantitative Modeling

Three linked models will be required to evaluate watershed/lake management strategies for Stoneman Lake: (1) a hydrologic and nutrient budget model; (2) a lake water quality model; and (3) a macrophyte model. Recommendations for each of these models are provided below.

2.5.1 Hydrologic and Nutrient Budget Model

In order to model water quality and macrophyte dynamics in Stoneman Lake, it will be necessary to estimate the amount of moisture and nutrients that both enter the lake and leave the lake over a period of time. Knowledge of the hydrologic budget of the lake is required to predict lake volumes, surface area and as a function of precipitation, temperature and watershed area. Knowledge of external nutrient fluxes is necessary to estimate changes in in-lake nutrient availability in response to changes in those fluxes.

Watershed loading models range from a simple empirical estimation of precipitation-runoff relations to complex deterministic models such as HSPF. A simple method is recommended for the Stoneman Lake watershed because:

- There are no streamflow or runoff water quality records from the Stoneman Lake watershed by which to calibrate a complex hydrologic model.
- Historical records of lake level are poor, also making model calibration difficult.
- A deterministic hydrologic model would require information on complex hydrologic processes (such as snow pack dynamics and groundwater flow) for which little to no watershed-specific information exists.

In other words, the benefits of hydrologic complexity are nullified by difficulties of parameter estimation and calibration. Several simple methods exist for estimating hydrologic and nutrient contributions from a watershed. These include the Simple Method, the Generalized Watershed Loading Functions (GWLF) and EPA Screening Procedures. All of these methods are basically equivalent and any would serve the purposes of this project.

A customized hydrologic/nutrient balance model that uses the Simple Method to estimate runoff-related fluxes of moisture and nutrients is recommended. Runoff coefficients and event mean concentrations can be estimated both from the literature and from a review of hydrologic and water quality from the Beaver Creek Evaluation Project for watersheds 8 and 13. Other moisture/nutrient fluxes can be estimated as follows:

- Direct precipitation can be estimated from nearby rain gages.
- Nutrient concentrations in precipitation can be estimated using monitoring results of the Beaver Creek Evaluation Project.
- Evapotranspiration can be estimated from estimates of local pan evaporation (~70 inches/year) and standard temperature-based equations.
- Groundwater discharge to Stoneman Lake can be estimated as precipitation minus runoff and evapotranspiration.
- Groundwater nutrient concentration can be estimated from ADEQ spring sampling results and Beaver Creek Evaluation Project baseflow sampling records.
- Groundwater recharge from Stoneman Lake cannot be easily estimated and so remains a calibration parameter.
- Wastewater loads will be estimated by applying various treatment efficiencies (e.g., 0-100% nitrogen removal) to estimated per-capita septage loads.

The hydrologic lake budget model could be adjusted by comparison to estimates of historical lake level made by the U.S. Forest Service and Malcolm Pirnie. The benefits of a custom model are that it can be run on a spreadsheet, easily altered by the user and customized to any desired time step. The model will have a daily time step due to daily precipitation records. However, in practice it would be used to predict hydrologic and nutrient fluxes on a seasonal or semi-annual basis.

2.5.2 Lake Water Quality Model

A steady-state eutrophication model is appropriate for Stoneman Lake and the model BATHTUB is recommended for this purpose. In contrast to commonly-used eutrophication models such as QUAL2E and WASP5, BATHTUB was developed specifically for lakes and reservoirs and it can be successfully applied as a screening application without a great deal of water quality data. The lake model PHOSMOD is not recommended because Stoneman Lake might have a nitrogen limitation during certain periods of the year. EUTROMOD would be the second choice for Stoneman Lake; however, this model was developed primarily for reservoirs in the southeast U.S. and the applicability of its empirical relations to Stoneman Lake is uncertain.

BATHTUB allows the user to segment the lake into a hydraulic network. While this is useful for flow-through reservoirs, it is unnecessary for Stoneman Lake because the hydraulic patterns in Stoneman Lake are not known and there is little advective flow in the lake. It is recommended to treat Stoneman Lake as a single segment with a single average depth for each model scenario.

2.5.3 SAV Model

It is important to note that BATHTUB and all the other models mentioned above were not designed to simulate water quality in macrophyte-dominated systems. If the macrophyte biomass is known or can be assumed, it can be ‘lumped’ with algae to predict water quality. However, BATHTUB cannot predict changes in macrophyte biomass, nor water quality for a scenario in which the macrophyte biomass is unknown. For this reason, it is recommended to link BATHTUB with the submerged aquatic vegetation (SAV) model developed by Carl Cerco (Waterways Experiment Station--U.S. Army Corps of Engineers) and Ken Moore (Virginia Institute of Marine Science).

The SAV model predicts SAV biomass as a function of nutrient limitations, water column light attenuation, leaf-surface light attenuation and self-shading. It was originally applied to the Chesapeake Bay system and is coded as a FORTRAN subroutine to the water quality model CE-QUAL-ICM. Application to Stoneman Lake will involve two principal changes to the model: (1) reconfiguring the code to make it independent of CE-QUAL-ICM; and (2) adjusting parameters to simulate the species in Stoneman Lake. As an example of the latter change, it may be necessary to adjust the SAV light requirement and/or photosynthesis rates to ensure that they are representative of milfoil. We are currently in communication with Drs. Cerco and Moore regarding these changes.

The SAV model has been primarily used to determine where SAV can be restored based on local water depth and water quality. Existing beds of canopy-forming species such as milfoil and coontail can actually live in water that is deeper than would be predicted for their restoration because they can send shoots up several meters in the water column. For this reason, it may be necessary to reduce or ‘turn off’ the water column light limitations for model scenarios that do not involve removal of existing shoots and roots.

2.6 Model Linkages, Calibration & Numeric Targets

The linked watershed-lake-SAV models will be developed to simulate steady-state summer time conditions and calibrated to accurately predict water quality conditions as measured by the Clean Lakes Program Similarly, the SAV model should be adjusted to predict full coverage of the bottom of Stoneman Lake under 1990s conditions. For each subsequent model scenario, the following iterative method is recommended to link the three different models:

1. Estimate the external nutrient loadings to the lake using the hydrologic and nutrient budget model.

2. Estimate internal lake recycling parameters for use in BATHTUB based on an initial estimate of the biomass and literature values.

3. Use BATHTUB to predict water column nutrient and chlorophyll concentrations.

4. Use the SAV model to predict SAV biomass based on the output of step 3.

5. Estimate nutrient recycling rate and mass of nutrients in SAV biomass based on results of step 4. If necessary, repeat steps 2-4 using adjusted nutrient recycling parameters.

6. Use BATHTUB to predict D.O. based on combined SAV and algal biomass.

Note that BATHTUB is used twice in two different manners. In step 3, it is used to predict algal biomass based on nutrient availability in the system, after ‘subtracting’ the nutrients that are associated with SAV biomass. D.O. cannot be predicted in step 3 because photosynthesis and respiration associated with the SAV are ignored. In step six, D.O. is predicted by calibrating BATHTUB to a chlorophyll concentration that is representative of the total (SAV + algae) biomass that was predicted from earlier steps.

3.0 MODEL SETUP

3.1 Watershed Loading Model

The watershed loading model for Stoneman Lake was developed in two steps. First, a water balance was performed on the lake by estimating the watershed yield of surface runoff/groundwater, direct precipitation on the lake surface, evaporation from the lake surface and groundwater recharge from the lake. This hydrologic model was calibrated to historical estimates of lake volume and level. Second, external nutrient loads were estimated by multiplying moisture fluxes by event mean concentrations (EMCs) and also by estimating nutrient loading from septic systems.

3.1.1 Hydrologic Model

The hydrologic model was developed to predict lake volume over the period 1958-1999. Earlier dates were excluded because of the lack of a precipitation gage in close proximity to the lake prior to 1958 and the fact that earlier attempts to estimate moisture fluxes to Stoneman Lake detected a significant change in the seasonal precipitation pattern starting around 1950 (U.S. Forest Service, 1981). It was first necessary to develop a bathymetric model that quantified the relations between lake level, surface area and volume. This was accomplished by combining information from the USGS digital elevation model and the bathymetric survey performed by ADEQ in 1999 (when the lake level was at an estimated 6721.5 feet asl) to create a surface of the lake bottom. The spatial Analyst tool of ArcView® was then used to calculate the lake volume and surface area for different lake levels, both including and excluding the impoundments (Table 3-1). The depth of the impoundments was assumed to be equal to the deepest part of the main lake.

The primary input data for the hydrologic model were precipitation data derived from two meteorological stations: the Beaver Creek Watershed 8 station operated by the U.S. Forest Service and the National Weather Service cooperative station at the Happy Jack Ranger Station (Figure 3-1). The Watershed 8 station was operated from 1958 to 1982, whereas the Happy Jack station has been in operation since 1968. For the period of overlapping records (1968-1982), data from the Watershed 8 station were used due to the greater proximity of this station to Stoneman Lake. These records were used to estimate the direct precipitation on the surface of Stoneman Lake.

Table 3-1

FIGURE 3-1

Watershed Yields:
In this report, a watershed yield coefficient is defined as the proportion of precipitation on a watershed that becomes streamflow at the mouth of the watershed. It represents all water falling on the watershed that does not evapotranspirate or infiltrate to deep groundwater. However, it includes groundwater that re-emerges as spring flow or base flow to a stream within the watershed. Average monthly and seasonal watershed yield coefficients for the Stoneman Lake watershed were determined by examining the relation between rainfall and streamflow in the Beaver Creek Watershed 8, where the U.S. Forest Service maintained a stream gage between 1958 and 1981. Watershed 8 is adjacent to the Stoneman Lake watershed, has similar geomorphic/land cover characteristics and was relatively undisturbed over the study period with the exception of some light thinning by the U.S. Forest Service.

The monthly variation in watershed yield (Table 3-2) reflects accumulation of snow within the basin during the winter and snowmelt in the early spring. For example, the average yield coefficient is greater than 1.0 for March and April, showing that much of the streamflow during those months was derived from snow and ice that fell in previous months. Because of the lack of information on snowpack within the watershed, it was decided to calculate seasonal rather than monthly watershed yields, using a two-season year: winter (October-April) and summer (May-September). Watershed yields calculated for the end of April and September will not contain errors caused by the presence of large amounts of unmelted snow in the watershed. The total watershed yield for each season was calculated as the product of the total seasonal precipitation, area of the Stoneman Lake watershed and the seasonal watershed yield coefficient. The model took into account the reduction in watershed size due to the temporary diversions in 1977-1980 and closure of the CCC ditch in 1982.

Table 3-2

Lake Evaporation and Loss to Groundwater:
Direct evaporation from the lake surface was assumed to be a constant 56 inches per year, 50 inches of which were assumed to occur during the summer (May-September). There was no available information on the magnitude of groundwater recharge from Stoneman Lake. Groundwater recharge was estimated during the model calibration as a means to avoid 'overfilling' the lake. The final calibrated value was 20,000 m^3/month during May-September and about 23,000 m^3/month during October-April, for a total of 260,000 m^3/ year.

Calibration:
The hydrologic model was calibrated by comparison of model-predicted lake volumes to historical lake volumes that were calculated from estimates of lake level by the U.S. Forest Service (1981) and Malcolm Pirnie. The historical lake levels were estimated from aerial photographs, lake depth measurements and anecdotal information. The primary calibration parameters were groundwater discharge and the watershed yield coefficient, which received small adjustments from the values obtained from Watershed 8 data. The final parameters of the calibrated model are presented in Table 3-3.

Calibration results (Figure 3-2) demonstrate that the hydrologic model accurately reproduces the historical pattern of lake volume and level, although the level of agreement in individual years is variable. The model apparently overpredicts the lake volume and level during the 1980s and 1990s, probably because it underestimates groundwater recharge when the lake level (and hydraulic gradient to groundwater) is high. Linear regression of the model-predicted volume v. historically estimated volume had an R^2 of 0.76 (Figure 3-3), indicating that the model captured 76 percent of the variability in lake volume estimates. The other 24 percent can be attributed to errors such as year-to-year variations in evaporation, groundwater recharge and water yield coefficients and to the fact that the precipitation measurements in Watershed 8 and Happy Jack are not exactly representative of the average precipitation in the Stoneman Lake watershed.

Table 3-3

Figure 3-2

Figure 3-3

3.1.2 Nutrient Loads

Seasonal nutrient loads to Stoneman Lake were estimated by multiplying average concentrations of nutrients in streamflow and precipitation by the watershed yield and direct lake precipitation values, respectively, from the hydrologic model. The mean concentrations for nitrate, ammonia and orthophosphate in precipitation were determined from analysis of precipitation water quality data collected by the U.S. Forest Service at multiple stations from the Beaver Creek watershed between 1977 and 1980 (Table 3-3). Average concentrations of nitrate, ammonia and orthophosphate in runoff/groundwater flow were determined from analysis of stream water quality data collected by the U.S. Forest Service Beaver Creek Watershed 8 between 1974 and 1980 (Table 3-3**)**. No direct information was available on the concentrations of organic nitrogen and particulate phosphorus in runoff. Total phosphorus in runoff was assumed to be 1.7 times the orthophosphate concentration, which is in the range normally encountered in natural systems (Walker, 1999). Total Kjeldahl nitrogen (TKN) in runoff was assumed to be three times the ammonia concentration, which is consistent with measurements made by ADEQ of TKN and ammonia in springs in the Stoneman Lake watershed.

Septic System Loads:
Total potential loads of nitrogen and phosphorus from septic systems to Stoneman Lake were estimated using the following assumptions:

- There are 70 total homes in the Stoneman Lake watershed, 2 of which are occupied year-round and 68 of which are occupied an average of 25 days per year by 3 persons.

- The average per capita loading of nitrogen and phosphorus are 12 and 2.5 g/day, respectively (Haith and others, 1996)

- Due to the uncertainty in the actual amount of septic-derived nitrogen and phosphorus reaching the lake, it was varied from 0 to 100 percent of the during the sensitivity analysis phase of modeling, as described in section 2.4.3. However, for the purposes of calibrating the lake model it was arbitrarily assumed that 75 percent of the total potential nitrogen load and 50 percent of the total potential phosphorus load reached the lake.

3.2 Lake Model (BATHTUB)

BATHTUB is an empirical eutrophication model developed by the U.S. Army Corps of Engineers and is documented by Walker (1999). It performs both water balance and nutrient balance calculations in a steady-state network of lake segments. Input data include lake geometry (average depth, surface area, etc.), hydrologic fluxes (tributary inflow, rainfall, etc.) and external nutrient loads. Output data include the predicted concentrations of nutrients, chlorophyll, hypolimnetic oxygen demand (HOD) and metalimnetic oxygen demand (MOD) in each lake segment.

BATHTUB was used to model Stoneman Lake as a single, horizontally-mixed segment. Because there is significant year-to-year variation in lake level, four different lake levels were modeled: 6717, 6720, 6723 and 6726 feet asl. 6726 feet represents the water level at the top of the dike and an average water depth of about 3.2 m, whereas 6717 feet represents an average depth of only about 1.1 m. The watershed loading model described in section 3.1 was used to estimate the average annual hydrologic and nutrient inputs that corresponded to the four different lake levels. External nutrient loads (except for nutrients in precipitation) were modeled as a tributary inflow to the lake. Precipitation loads and lake evaporation were made consistent with those used in the watershed loading model. Due to the relatively long hydraulic and nutrient residence time of Stoneman Lake (see section 2.1), a full year was selected as the averaging time for hydrologic and nutrient loads to the lake.

Other BATHTUB-specific parameters used for Stoneman Lake are summarized in Table 3-4. It was determined that there was insufficient information on sediment nutrient release rates to explicitly specify sediments as a nutrient source. Instead, internal recycling of nutrients within the lake was implicitly modeled by adjustment of the nitrogen and phosphorus sedimentation rates. For example, the net uptake of nutrients by SAV during the growing season was modeled by increasing the nutrient sedimentation rates to match observed water quality data.

Calibration:
BATHTUB was calibrated to water quality data collected by ADEQ during the 1990s on summer (May-September) days when the lake level was estimated to be near the modeled lake levels. Summer conditions were chosen for calibration because they represent critical conditions for water quality and SAV growth. The primary calibration parameters were the BATHUB calibration factors for nitrogen and phosphorus sedimentation rate and chlorophyll response.

Table 3-4

3.3 SAV Model

Prior to calibration, BATHTUB predicted much higher chlorophyll and phosphorus concentration than have been observed in Stoneman Lake. A major reason for this is that BATHTUB was not designed to predict SAV growth and nutrient interactions; i.e., the lakes and reservoirs upon which BATHTUB was developed were not macrophyte-dominated. In Stoneman Lake, the dominance of SAV over algae in competition for nutrients and light results in much lower algae/chlorophyll concentrations than would be expected in a non-macrophyte-dominated system. After adjustment of the nutrient sedimentation and chlorophyll response calibration factors, BATHTUB adequately reproduced observed water quality conditions for three out of the four lake levels (Figure 3-4). Discrepancies for the model of a lake level of 6723 are caused by abnormally low phosphorus and chlorophyll concentrations on the date chosen for comparison.

The inability to consider SAV growth is a major limitation of the application of models such as BATHTUB to macrophyte-dominated systems such as Stoneman Lake. Under summer conditions, SAV is usually the largest source of oxygen demand in macrophyte-dominated lakes and also exerts a strong control on algal growth. Therefore, it was desired to utilize another tool that could predict changes in SAV growth in response to different lake/watershed management scenarios. The model chosen for Stoneman Lake was a modified version of the SAV model developed for the Chesapeake Bay Program by the U.S. Army Corps of Engineer-Waterways Experiment Station and the Virginia Institute of Marine Science. The theory of this model is documented by Cerco and Moore (in press).

As applied to the Chesapeake Bay, the SAV model was a dynamic simulation of SAV root and shoot growth as a function of light and nutrient availability and temperature. It considered both water column light attenuation and leaf-surface light attenuation caused by epiphytic growth. The model considered nutrients available to SAV from the water column and from sediments. Other major input data to the Chesapeake Bay SAV model included kinetic parameters describing nutrient uptake, respiration, transfer of production between roots and shoots and sloughing. Most of these parameters vary between freshwater, mesohaline and polyhaline plant species. The model was executed as a subroutine to the CE-QUAL-ICM model of the hydrodynamics and water quality of the Chesapeake Bay.

Several simplifications to the SAV model were made for application to Stoneman Lake. First, it was used to estimate the *peak* SAV biomass in the lake rather than a growth-death curve over the growing season. This was accomplished by solving the model equations for conditions in which the rate of change of shoot biomass with time was zero. The root biomass at the time of peak SAV biomass was assumed to be about 14 percent of the total SAV biomass, based on values reported for Eurasian water milfoil by Grace and Wetzel (1978). Model parameters (Table 3-5) were selected to be representative of a general freshwater species during the middle of the summer, largely based on personal communications with model co-developer Dr. Ken Moore of the Virginia Institute of Marine Science. Upon the advice of Dr. Moore, light attenuation by epiphytic growth on leaf surfaces was ignored due to its relative unimportance in freshwater systems.

Figure 3-4

Table 3-5

Like BATHTUB, the SAV model was used to simulate four different lake levels: 6717, 6720, 6723 and 6726 feet asl. Input data to the SAV model included water column nutrient and chlorophyll concentrations from BATHTUB. Sediment nutrient concentrations were obtained from ADEQ measurements of leachable nutrient concentrations in sediments in Stoneman Lake. The secchi depth was specified as a constant 3.5 m, which is consistent with the TSS and chlorophyll concentrations observed in Stoneman Lake. The water column light attenuation coefficient (k_d) was then calculated as 1.7/secchi depth.

During sensitivity analysis, it became clear that the SAV model was moderately sensitive to the depth of the leaf surface, which for a particular lake level will be a function of the maximum height of the shoot in the water column. For example, if the water depth is 4 m, much more light will be available to the shoot if it can grow 4 m tall than if it can only grow 2.5 m tall. Milfoil will usually reach the surface in water depths of less than 2.5 m. Grace and Wetzel (1978) report that milfoil shoots can grow in excess of 4 m. Therefore, the SAV model was executed twice for each lake level, with the assumptions that the SAV can grow to 2.5 m and 4 m lengths, respectively.

Calibration:
Due to lack of quantitative information on the SAV biomass density and coverage, it was not possible to calibrate the SAV model. Rather, the model results may be interpreted as uncalibrated estimates of the potential SAV growth in response to nutrient and light availability. For lake levels of 6717-6726 feet asl, the SAV model predicted peaked SAV biomass densities of 400-600 g/m^2. These values are within the expected range of 100-1,000 g/m^2 that commonly measured in macrophyte-dominated lakes.

3.4 Dissolved Oxygen Demand and Diurnal Range

Rather than predicting D.O. concentration, BATHTUB predicts the hypolimnetic and metalimnetic oxygen demands (HOD and MOD), with the assumption that the lake is well stratified. Although Stoneman Lake does exhibit vertical D.O. stratification in the summer, the extent of vertical mixing is expected to be highly dependent on the presence or absence of a thick SAV canopy. The shallowness of Stoneman Lake will reduce the thermal stratification that is the major cause of hypolimnion formation in most lakes. Moreover, BATHTUB was designed to predict HOD and MOD as a function of algal growth rather than SAV growth. Therefore, for Stoneman Lake it is not reasonable to compare BATHTUB predictions of HOD and MOD between model scenarios. The alternate approach used for Stoneman Lake involved estimation of: (1) biological oxygen demand (BOD) from primary production; and (2) the diurnal range in D.O.

The total BOD from primary production is a function of the total SAV and algae biomass produced over the growing season. The total SAV biomass was estimated as two and a half times the peak SAV biomass, which is typical of macrophyte-dominated lakes. The average daily algal production was estimated as follows (modified from Thomann and Mueller, 1987):

$$B_a = a_{cP} G_p P \quad (1)$$

where:

B_a = algal production rate, mg C L^{-1} day^{-1}
a_{cP} = carbon: chlorophyll ratio
G_p = chlorophyll production rate, day^{-1}
P = chlorophyll concentration from BATHTUB, mg chlorophyll L^{-1}

The chlorophyll production rate was estimated as function of nutrient and light availability as follows (modified from Thomann and Mueller, 1987):

$$G_p = G_{\max}(1.066)^{T-20} G(I_a) \bullet \min\left\{\frac{N}{K_{mN} + N}; \frac{p}{K_{mP} + p}\right\} \quad (2)$$

where:

G_{max} = maximum chlorophyll production rate, day^{-1}
T = water temperature, °C
$G(I_a)$ = limitation due to non-ideal light conditions, dimensionless
N = dissolved inorganic nitrogen concentration from BATHTUB, mg L^{-1}
p = dissolved inorganic phosphorus concentration from BATHTUB, mg L^{-1}
K_{mN} = half-saturation constant for nitrogen, mg L^{-1}
K_{mP} = half-saturation constant for phosphorus, mg L^{-1}

Table 3-6 provides a list of the constants and parameters used in equations 1 and 2. In order to produce a conservative but reasonable estimate of BOD, these values were chosen to represent moderate-to-high rates of algal production. After the seasonal SAV and algal biomass was estimated, the average daily BOD production over a six-month growing was estimated as:

$$BOD_d = 2.67(1 - f_r)(B_a + SAV_d) \quad (3)$$

where:

BOD_d = average daily BOD produced over the growing season, mg L^{-1}
2.67 = stoichiometric oxygen equivalent of carbon
f_r = percent of refractory carbon
SAV_d = average SAV production over the growing season, mg C L^{-1} day^{-1}

Table 3-6

The diurnal range in D.O. was estimated as a approximately half the average gross photosynthetic production of D.O. after Di Toro (1975), assuming a relatively low reaeration rate for Stoneman Lake. The D.O. production rate of SAV was assumed to be 88 mg O_2 day^{-1} g dw^{-1}, which is representative of Eurasian watermilfoil (McGahee and Davis, 1971). The D.O. production rate of algae was calculated using the following equation (modified from Thomann and Mueller, 1987):

$$p_a = a_{op} G_p P \quad (4)$$

where:

p_a = daily oxygen production, mg L^{-1} day^{-1}
a_{op} = ratio of mg D.O. / mg chlorophyll, assumed to be 200

3.5 Model Scenarios

As discussed in section 3.0, the major watershed/lake management alternatives that were considered for Stoneman Lake include the following:

SAV harvesting
Herbicide application
Biological controls
CCC ditch regulation
Dredging
Septic system upgrades
Aeration

3.5.1 SAV Removal

Alternatives 1, 2 and 3 all represent the removal of SAV from the lake and/or the prevention of SAV growth. Therefore, all three alternatives were modeled as an SAV removal scenario. This was accomplished by executing BATHTUB without any adjustments to calibration factors for nitrogen and phosphorus sedimentation rate or chlorophyll response; i.e., keeping all calibration factors equal to 1.0. In this manner, the BATHTUB model predicts the expected water quality response of Stoneman Lake to the hydraulic and nutrient loading without "forcing" the model to simulate the dominance of SAV over algae in competition for nutrients and light. The results reflect what BATHTUB predicts Stoneman Lake would be like if it were not macrophyte-dominated.

The scenario described above contains the assumption that the presence of SAV is the only reason that the calibration parameters for Stoneman Lake differ from the 'average' lake used in the development of BATHTUB. In reality, there may be other reasons that algal growth in Stoneman Lake is low: temperature effects, excess radiation, grazing, etc. However, this assumption provides a conservative estimate of the potential algal growth in Stoneman Lake.

3.5.2 Variable Lake Depth

Alternatives 4 and 5 would potentially result in higher lake levels and greater lake depths. The effect of greater depths on water quality and SAV growth is considered by comparison of the model for four different lake level models: 6717, 6720, 6723 and 6726 feet. The 6726 model represents conditions under which the lake level is at the top of the dike system, whereas the 6717 model represents only about 1.1 m of water in the lake (Table 3-1). Because BATHTUB and the SAV model primarily consider lake depth rather than lake level (elevation), the high lake level scenarios also can be interpreted as deeper lake scenarios due to dredging. The actual impact of ditch regulation and dredging on lake depth is discussed further in section 4.0.

3.5.3 Septic System Upgrades

There are insufficient groundwater monitoring data to quantify the impact of septic systems on nutrient concentrations in groundwater seeping into Stoneman Lake. Due to this lack of information, the septic system upgrade scenario was handled in the form of a sensitivity analysis. The loads of nutrients from septic systems to the lake were modeled in BATHTUB using three different assumptions:

- 100 percent of potential nitrogen and phosphorus loads from septic systems enter the lake
- 100-precent of the potential nitrogen load and 0 percent of the potential phosphorus load from septic systems enter the lake
- 0 percent of potential nitrogen and phosphorus loads from septic systems enter the lake

In this manner, the sensitivity of the lake water quality to septic load may be assessed, as well as the maximum potential benefit of septic system upgrades.

4.0 MODEL RESULTS

The linked watershed, lake and SAV models described in section 3.0 were used to predict current lake conditions as well as implementation scenario conditions. The major output results of interest include predictions of the following:

Nutrient concentrations
Chlorophyll concentrations / algal biomass
SAV biomass
Biological oxygen demand (BOD) due to primary production
Diurnal range in D.O.

This section summarizes the results of each model scenario with respect to these parameters.

4.1 Existing Conditions

Existing water quality and SAV conditions for Stoneman Lake are discussed in section 2.1.1. Model results provide insight into several other interesting characteristics of Stoneman Lake and its watershed.

External Nutrient Sources:
The watershed loading model predicts that direct precipitation is the single largest source of nitrogen to the lake in an average year (Figure 4-1). This is largely due to the fact that dissolved nitrogen concentrations are actually higher in precipitation than in runoff, as measured by the U.S. Forest Service in the Beaver Creek watershed. As in many forested regions, flora and soil microorganisms sequester much of the dissolved nitrogen that falls on the land surface. Direct precipitation and runoff provide approximately equal amounts of phosphorus to the lake. Septic systems would provide an estimated 12-percent of the nitrogen and 6-percent of the phosphorus entering Stoneman Lake in an average year, but would provide higher percentages in an unusually dry year.

Nutrients in SAV Biomass:
The SAV model predicts an average peak biomass density of about 600 g dw/m^2. Assuming that SAV tissue is composed of 2.5-percent nitrogen and 0.5-percent phosphorus, the SAV biomass in Stoneman Lake contains about 10,000 kg nitrogen and 2,000 kg phosphorus. Comparing these figures to the predicted external loads of 560 kg nitrogen and 160 kg phosphorus per year reveals that the SAV biomass contains 12-18 times more nutrients than the annual external load. Therefore, it may be concluded that internal recycling is the major source of nutrients to SAV in an average year.

Figure 4-1

Residence Times:
Another model result of note is the prediction of very long residence time of water and chemical constituents in Stoneman Lake. BATHTUB predicts an average hydraulic residence time of about one year, compared to several weeks or months for most flow-through reservoirs. Even more striking is that the predicted average residence time of a conservative substance (one that cannot leave the lake by evaporation) is about four years, compared to several weeks or months for most flow-through reservoirs. From these results it becomes clear that, although external nutrient loads to Stoneman Lake are not extremely high, the lack of a surface-water outlet causes whatever enters the lake to remain there for a long period of time and in fact to be concentrated by evaporation. Thus, the hydraulics of Stoneman Lake are at least as important as external loads in controlling nutrient concentrations.

4.2 SAV Removal

As discussed in section 2.5.1, the effect of SAV removal/growth prevention by harvesting, herbicides, or biological controls may be estimated by comparing the results of calibrated and uncalibrated BATHTUB models. The uncalibrated model provides a prediction of what Stoneman Lake would be like without nutrient uptake and shading by SAV. A lake level of 6720 was chosen for comparison of the two models, because it is representative of the average summer lake level between 1982 and 1999.

4.2.1 Effect on Nutrients and Chlorophyll

Results (Table 4-1) demonstrate that, in the absence of SAV, there is the potential for Stoneman Lake to convert to a hypereutrophic, phytoplankton-dominated system, as represented by chlorophyll concentrations greater than 50 µg/L. In other words, without competition from SAV, BATHTUB predicts that algal biomass could increase to more than ten times its present summer average. As discussed in section 2.3.3, this is a conservatively high estimate of potential chlorophyll concentrations because it requires the assumption that the presence of SAV is the only reason that algal growth in Stoneman Lake presently departs from the ‘average’ lake or reservoir, given the lake’s morphology and external loads. However, the results clearly demonstrate that Stoneman Lake will retain a high rate of primary production, either in the form of SAV or in the form of algae. Nutrient concentration are predicted to increase after SAV removal (Table 4-1) due to lower rates of uptake.

4.2.2 Effect on D.O.

The D.O.-related calculations described in section 2.4 were performed to determine if D.O. would be expected to be significantly better or worse in a phytoplankton-dominated lake than a macrophyte-dominated lake. Results (Table 4-1; Figure 4-2) demonstrate that the average daily production of BOD would be expected to be comparable in a phytoplankton-dominated lake as in a macrophyte-dominated lake. Although SAV attains a higher *peak* biomass, algae have a higher growth/turnover rate and produce as much or more *total* biomass over the growing season. In contrast, an SAV-dominated lake would be expected to have up to an 11 mg/L higher diurnal range of D.O. during peak growth, largely due to the higher peak biomass of

SAV.
Table 4-1

Figure 4-2

The removal of SAV would benefit D.O. in one manner that the model does not quantify; namely, it would improve vertical mixing. Low D.O. conditions were apparently responsible for only one fish kill during the 1990s (in 1995), probably because the fish can almost always find sufficient D.O. in the upper water column, above the SAV canopy. Removal of the canopy would be expected to eliminate or greatly reduce the vertical stratification and thus provide more D.O. to the lower water column. In contrast, even moderate rates of primary production will be sufficient to cause D.O. impairments in the lower water column as long as the SAV canopy remains.

It should be noted that alternatives that kill SAV but do not remove it from the lake (e.g., cutting, herbicide application) will cause the SAV-decay-related oxygen demand to be exerted in a short period of time after the action in implemented, due to the decay of the SAV biomass. D.O. impairments would almost certainly follow.

4.3 Variable Lake Level

The level of Stoneman Lake exhibits a large year-to-year variation in response to changes in precipitation and other meteorological factors, so the variable lake level scenarios do not necessarily represent new conditions for the lake. However, reopening/regulation of the CCC ditch would result in higher average lake levels, as would dredging to a lesser degree. The purpose of these model scenarios to examine the sensitivity of water quality and SAV biomass to lake level.

4.3.1 Effect on Nutrients and Chlorophyll

BATHTUB results demonstrate that both nutrient concentrations and chlorophyll concentrations are expected to decrease slightly at higher lake levels (Table 4-1; Figure 4-3). The decrease in predicted nutrient concentrations is modest because more nutrients enter the lake during wet years than dry years. Similarly, chlorophyll concentrations are relatively insensitive to lake level because the higher the lake level, the more water volume available for algal growth.

4.3.2 Effect on SAV

For all model scenarios, the SAV model predicted that the reduction of light by self-shading of SAV would be the greatest limitation on SAV growth during the middle of the growing season. As a result, the predictions of peak biomass are insensitive to changes in nutrient concentrations or loads. Similarly, the high water clarity results in little limitation of SAV by water-column light attenuation even with a high lake level. A high lake level is predicted to cause modest reductions in peak SAV biomass if the SAV can only grow to a height of 2.5-m (Table 4-1) and little to no reduction if the SAV can grow to a height of 4 m. In short, the SAV model demonstrates that peak SAV biomass in Stoneman Lake would probably not decrease significantly in response to a 1-2 m higher average lake level. The biggest effect on SAV would be slower growth early in the growing season; i.e., a longer time to reach the peak biomass.

Figure 4-3

4.3.3 Effect on D.O.

Just as the SAV biomass is relatively insensitive to changes in lake level, the total D.O. demand of that biomass is also insensitive. However, at a higher lake level that demand would be 'diluted' in a greater volume of water and thus a higher lake level would reduce BOD as expressed in mg/L (Table 4-1). If the lake were completely mixed, there would be a predicted 71-percent reduction in BOD between a lake level of 6717 and 6726 feet, even assuming the SAV could grow to a height of 4 m (Figure 4-4). In reality, the SAV canopy will reduce vertical mixing and much of the D.O. demand will occur in the lower portion of the water column, potentially causing hypoxia even during high lake levels. However, the BOD dilution effect is expected to significantly increase D.O. concentrations in the middle and upper portion of the water column. The water quality standard for D.O. applies at depths of 1 m and less, so a higher lake level has the potential to reduce violations even if the lower water column remains hypoxic.

4.3.4 Effect of Alternatives on Lake Level

In an attempt to estimate the effect of the CCC ditch on the level of Stoneman Lake, the hydrologic model was run under three conditions: (1) historical, described in section 2.1.1; (2) as if the ditch were open for the entire period 1958-1999; and (3) as if the ditch were closed for the entire period 1958-1999. Results (Figure 4-5) demonstrate that flow from the CCC ditch can significantly increase the average lake level. Historically, the average lake level was actually lower when the ditch was open (pre-1982) than when it was closed. This was primarily due to the fact that precipitation levels were much lower in the 1960s and early 1970s than in the 1980s. Very high precipitation levels in the 1980s kept the lake level high during this period. However, precipitation returned to more normal levels during the 1990s, with the result that the lake level showed a steady decline over this decade that has continued to the present day.

The lake went dry in 1965. Interestingly, the 'closed-ditch' model suggests that the lake might have go dry three additional times during the 1960s and 1970s if the CCC ditch had been closed. Similarly, if the ditch had been open during the 1980s, the high precipitation levels would have caused much higher lake levels during this period, probably overtopping the dike in the spring of several years. The models predict a average lake level of 6719 ft if the ditch were closed during 1958-1999, compared to an average of 6726 feet if the ditch were open over the entire period. As stated earlier, the model overpredicts lake level during the 1980s and 1990s due to the underestimation of groundwater recharge when lake level is high and thus the 'open ditch' lake level average is a conservatively high estimate. Even if the actual value is several feet lower, the model shows that an unregulated, open ditch would significantly increase the frequency of water overtopping the dike. However, reopening and regulation of the CCC ditch could protect the lake from going dry during dry periods and would significantly increase the average lake level during periods of normal precipitation.

Dredging the lake alone would probably not have as large an impact on lake level as CCC ditch regulation, because without additional runoff into the lake it would probably just fill to a lower level. A deeper lake would collect more groundwater discharge that was previously flowing beneath the lake and thus the lake depth would be expected to increase somewhat. However, the magnitude of such an increase cannot be quantified at this time.

Figure 4-4

Figure 4-5

4.4 Septic System Upgrade

The peak SAV biomass is relatively insensitive to external nutrient loads and thus SAV and SAV-related D.O. impairments showed little response to reductions in nutrient loads from septic systems. BATHTUB was utilized to evaluate potential reductions in nutrients/chlorophyll assuming removal of the SAV and subsequent conversion to a phytoplankton-dominated system. As described in section 3.5.3, the potential benefits of septic system upgrades were evaluated by comparing three scenarios for an average lake level of 6720: (1) 100-percent of the septic nitrogen and phosphorus reaching the lake; (2) 100-percent of the septic nitrogen and 0-percent of the septic phosphorus reaching the lake; and (3) 0-percent of the septic nitrogen and phosphorus reaching the lake.

BATHTUB predicted negligible reductions in chlorophyll/algal growth for septic scenario 2 compared with septic scenario 1 (Table 4-1; Figure 4-6). This is because BATHTUB predicts more of a nitrogen limitation on algal growth than a phosphorus limitation and because septic systems contribute only 6-percent of the total annual phosphorus load. In contrast, septic scenario 3 showed a significant reduction (19-percent) in chlorophyll/algal growth compared to septic scenario 1.

Although the water quality of Stoneman Lake is not highly sensitive to septic nutrient inputs, it should be noted that there are other water quality and sanitary benefits to upgrading septic systems. Several of the existing septic drainfields are within the 100-year floodplain of the Stoneman Lake and upgrade would reduce the risk of contaminating surface water with fecal coliform bacteria and other pathogens.

Figure 4-6

5.0 FEASABILITY AND COST OF ALTERNATIVES

In conjunction with computer modeling of water quality benefits, the major alternatives were evaluated with regard to cost, technical feasibility, environmental impacts and regulatory issues. Based on a review of lake/watershed management techniques and discussions with watershed stakeholders, seven major management techniques were considered:

1. SAV harvesting/cutting
2. Herbicide application
3. Biological controls
4. CCC ditch regulation
5. Dredging
6. Septic system upgrades
7. Aeration/artificial circulation
8. Regulatory redesignation

The eighth alternative, termed regulatory redesignation, although considered, is not a lake watershed/watershed management technique but would involve altering the water quality standard for Stoneman Lake.

Aquatic weed harvesting by mechanical equipment is commonly performed in lakes and ponds to control SAV growth. The major advantage is that it creates an immediate response by removal of most of the plant material. However, harvesting is very labor intensive. Cutting is a related method that does not involve removal of the cut plant material from the water body.

5.1 SAV Harvest (Removal) or Cutting

5.1.1 Feasibility and Environmental Issues

Cutting would require the more basic harvester machinery and demand the least amount of time and money of all the harvesting methods. The AGFD has performed this work at Stoneman Lake in the past. They reported that this was the only alternative at Stoneman Lake because they could not access the lake with their larger harvester. Because cutting would exacerbate rather than reduce D.O. impairments in Stoneman Lake (see section 4.2.2) , it is not considered a viable alternative. In addition, cutting has the potential to increase the growth rate of plants that reproduce through fragmentation (e.g., Eurasian watermilfoil). Therefore, cutting is not considered further in this section.

At an average rate of 0.4 acres per hour and a 40-hour workweek, it would require about seven and a half weeks to harvest 120 acres of Stoneman Lake. Harvesting would need to be repeated every one to three years, depending on the growth rate of the plants and the harvesting method used. The root-crown harvesting method is the most labor intensive of all the harvesting operations. Since the entire plant is removed from the water body, this method has a longer lasting effect, as much as three years, when compared to other harvesting techniques. Most commercial harvesters remove only the upper portion of the plant, leaving the root intact. In this case, it would probably be necessary to repeat harvesting at least every other year. The harvester machinery is operable in water depths between two and five and one half feet. As much as 30 percent of Stoneman Lake might not be accessible to harvesting equipment.

Once harvested, the plant material, or spoils, would have to be removed from the lake and disposed of. The least costly way to approach this issue would be to work with the U.S. Forest Service to find an area near the lake to place the spoils. The AGFD has had success depositing their spoils on U.S. Forest Service land in the past. Further coordination with the U.S. Forest Service would be required in order to determine whether a feasible spoils disposal site can be located.

Aquatic weed harvesting is generally of low impact to the environment and has no major legal issues or permitting associated with it. However, harvesting may be somewhat disruptive to the water clarity, causing short-term increases in turbidity and nutrient concentrations, due to the sediment disturbance and plant removal. Algal blooms may also occur following harvesting as a result of sediment nutrient release. In addition, the equipment and trailer are rather large (about 43 feet long x 10 feet wide x 9 feet tall for the HM-420, Aquarious Systems ®) and may be difficult to maneuver down the access roads to Stoneman Lake.

5.1.2 Costs

Harvesting could be performed on contract by a lake management company or by the AGFD, both using their own equipment. Alternately, harvesting equipment could be purchased specifically for Stoneman Lake.

Contracted harvesting:
The harvesting of aquatic plants by private companies has become common in many states. Tite Enterprises of Sylmar, California (Tite) state that it would be possible to harvest Stoneman Lake at a rate of about four surface acres/day. Their costs would also include the travel time and per-diem for out of town work. Tite stated that a rough estimate for a full lake treatment might be about $5,000 to $8,000.

The AGFD currently performs many harvesting operations throughout the State of Arizona. Numerous interviews were conducted with various members of the AGFD. None of the employees were able to offer cost estimates, but it was stated that their costs would be similar to those of the private sector. Because the AGFD is a government agency, differences in costs may still be considerable when compared to the private sector. More specifically, there could be significant differences in the actual cost paid, the method of payment and the ability to provide hauling and storage areas for the spoils.

Equipment purchase:
As an alternative to contracting either the AGFD or a private company to harvest, an aquatic weed harvester

could be purchased and stored at the lake. Aquarius Systems of North Prairie, Wisconsin, sells appropriately sized harvesters at a cost of about $80,000 to $100,000, depending on the size. Included in a harvester purchase is a shoreline conveyor (to remove the weeds from the lake), trailer, transportation costs and two days of training. The average life expectancy of a harvester is about thirteen years and the maintenance cost for a harvester is estimated to be about $1,000 per year. If harvesting required 30 days per year, labor costs for a harvest could be about $2,500/year, not including training costs.

A protective storage facility would also be recommended for the equipment. A properly sized steel storage shed is estimated to cost about $25,000, while an engineered fabric wrapped aluminum structure may cost about $12,000. An improved boat ramp, costing $4,000 to $5,000, would be required so that the harvesters could access the lake.

Disposal costs:
Most harvesting operations leave the spoils at the shoreline. A large part of the expense for harvesting operations involves the removal of the spoils from the watershed. It would be necessary to contract with a hauling or excavation company for the use of a loader and at least two dump trucks for approximately a week. If the U.S. Forest Service is willing to allow the spoils to be stored on their land costs could be greatly reduced. Assuming that a location for the storage of spoils is within three miles (i.e., on U.S. Forest Service property) the cost for spoils disposal might be as low as $5,000. Conversely, the landfill fees for the estimated quantities of weeds at Stoneman Lake could run over $100,000 per harvest.

5.2 Herbicide Application

Herbicides can be very effective at controlling invasive aquatic weed vegetation. However, the effectiveness, cost and environmental risk varies considerably with the specific chemical used. In reviewing the appropriateness of various herbicide to Stoneman Lake, the following issues were considered:

- The physical characteristics of Stoneman Lake, such as surface area, drainage conditions, residence times, volume and its use for wildlife habitat.
- The targeted species of SAV (e.g., Eurasian watermilfoil and coontail)
- Water quality considerations. A slow-acting chemical was desired to avoid lowering D.O. concentrations by causing a sudden die-off.
- Recreational demands. The uninterrupted use of the lake by all recreationists was desired.

5.2.1 Feasibility and Environmental Issues

Inquiries and discussions with AGFD did not reveal any current state, local or federal issues controlling the use of aquatic herbicides, other than the federal requirement that application is performed in accordance with the manufacturer's instructions. However, greater regulation of aquatic herbicides may occur in the near future. In February 1999, President Clinton signed an Executive Order that established an Invasive Species Council and requires this Council to prepare an Invasive Species Management Plan. One possible outcome of the Management Plan would be to recommend more federal regulation in order to control the introduction and spread of invasive species. Because the use of chemical herbicides can often raise many questions with the local public, this alternative should be thoroughly reviewed with regard to its acceptance by concerned citizens prior to its use.

The herbicide that best met the requirements listed above and is the most highly recommended for Eurasian watermilfoil control is Sonar® A.S. by Sepro®. Sonar® has only one listed restriction for irrigation, but has no swimming, drinking, or fishing restrictions. There are about twenty-five different aquatic plant species that are at least partially affected by Sonar®. This is a relatively small number when compared to other popular aquatic herbicides, such as Navigator by Sepro®, or Reward® by Zeneca®. In addition, Sonar® has the longest lasting effects and in some cases may only require an application every three years. Each application will remain effective for over twelve months depending on the application concentration and other factors. This product may have minor deleterious effects to non-targeted species, such as color staining. For these reasons, combined with the popularity of Stoneman Lake for recreationists, Sonar® is the safest and best herbicide available.

Although Sepro® has stated that it is very rare for Sonar® to affect non-targeted species or have a deleterious effect on the biota of a water body, this can not be accurately ascertained prior to its application. The effectiveness and efficiency of any herbicide can only be demonstrated in the field at the location in question. If this alternative is implemented, it is recommended that the herbicide be applied at a very low concentration and in a limited area.

5.2.2 Costs

Sonar® can be applied either in a dry or liquid mixture form. An initial low concentration application (about 20 parts per billion) of this product at Stoneman Lake was recommended by Marine Biochemists®. Their cost range was from $13,000 to $25,000 and included the labor as well as the purchase of the chemicals.

5.3 Biological Controls

Biological controls include the introduction of herbivores, insects, or pathogens into the environment to combat the targeted plant species. The most common biological control involves the stocking of a lake with Asian triploid grass carp (herein referred to as carp or fish and most of the following discussion focuses on carp. The possibility of using the milfoil weevil (*Euhrychiopsis lecontei*) was also investigated; this insect has been shown to be effective in Vermont and Wisconsin for selectively controlling Eurasian watermilfoil. However, it was determined Stoneman Lake is not an appropriate location for this method because, in the absence of milfoil, there would still be high rates of growth of other species such as coontail and pondweed.

5.3.1 Feasibility and Environmental Issues

Grass carp stocking to control SAV growth has been successful at a number of locations around Arizona, including high elevation near Flagstaff. There are no known cases of serious detrimental impacts on water bodies due to the stocking of grass carp. The only exception to this statement might be the occurrences when too many carp are used causing eradication of SAV in the water body. This can usually be controlled through careful monitoring and low stocking rates.

About six to 10 months after this initial fish stocking a survey should be conducted to assess the overall efficiency of the carp. At this low stocking rate it is likely that another three to five fish per surface acre would be required. Growth rate, diet and many other variables would control the overall effectiveness of grass carp at Stoneman Lake. Grass carp stocking should be done using a serial (i.e., closely controlled and managed) approach so that an adequate plant to fish ratio can be maintained. If these procedures are followed, it is likely that within one to three years the grass carp could control SAV growth. The active life expectancy of these carp is about six years and so there would be a need for periodic restocking.

5.3.2 Costs

An average carp stocking rate would be about five to seven fish per surface acre. Because the overall efficiency of biological controls is difficult to predict, it is recommended that a three to five fish per surface acre ratio be used to avoid overstocking. These fish can then be monitored throughout the following year for determinations on overall effectiveness. Following these procedures (without monitoring costs) it is likely that the costs would be as follows:

3 fish/surface acre x ~$12.00/fish x 125 surface acres
+ ~$500 (transportation costs) = ~$5,000

The AGFD requires that permits are filed and accepted with their offices prior to any stocking operations. These costs run about $100 to $200 per year.

5.4 CCC Ditch Regulation

Reopening of the CCC ditch would increase the area's watershed by approximately one third and would help maintain higher average lake levels as described in section 4.3.4. The major risk associated with the CCC ditch is increased flooding of property on the lakeshore. Therefore, it would be necessary to not just reopen but regulate the ditch to minimize this risk. This could be accomplished by the construction of a simple hydraulic control structure near where the ditch enters the lake (Figure 5-1). The hydraulic control structure could consist of a simple headwall, canal gate and overflow weir system (Figure 5-2). Some earth moving work would also be required to remove obstructions in the ditch and repair breaches in the downslope embankment.

5.4.1 Feasibility and Environmental Issues

Regulation of the ditch will not prevent the lake from going dry in extremely dry periods, as evidenced by the lake going dry in 1965 with the ditch open. Similarly, closing the ditch it will not prevent the lake level from rising above the dike during extremely wet years, as evidenced by the high lake levels of 1980 when the ditch was diverted. However, model results demonstrate that the regulation of ditch has the potential to reduce the frequency of the lake going and dry and will maintain higher lake levels in years of normal precipitation.

Hydrologic formula:
In order to prevent flooding during wet periods, the regulation of the ditch could be accomplished with a hydrologic formula that considers existing lake level and snowpack in the watershed, with a margin of safety for unanticipated hydrologic events. For example, in some years the lake level might be so low that snowmelt/precipitation over the combined natural/ditch watershed will not cause the lake level to overtop the dike. In other years, it may be determined that snowmelt from the natural watershed alone is sufficient to reach desired lake levels. This approach is recommended over simply maintaining the lake at a given level, because such a method would not sufficiently reduce the flooding risk in extremely wet years.

The costs of ditch regulation would include the costs of monitoring equipment to collect the hydrologic information needed for the regulation formula, including a lake level gage, a precipitation gage, a snow pack gage and a stream gage for the ditch. The costs would also include a hydrologic modeling study to derive the formula. The hydrologic model developed for the present study is insufficient for ditch regulation because it does not explicitly consider snow pack and was intended to predict the average lake response to precipitation rather than accurately predict the lake level in individual years.

Regulatory issues:
Geographically, Stoneman Lake falls within the upper Verde River valley, where most water rights are controlled by the Salt River Project (SRP). SRP has indicated that it would not contest the reopening of the CCC ditch if there was an existing water right or an application for a water right that had not been contested (S. Fitch, ADEQ, elec. comm., 6 June 1000). A preliminary investigation into the water rights of the CCC ditch suggests that since 1919 the U.S. Forest Service has held a water right of 0.2 acre-feet/year associated with Stoneman Lake (S. Fitch, ADEQ, elec. comm, 6 June 2000). This volume would be insufficient to significantly raise the lake level; the average potential flow from the CCC ditch watershed to the lake is closer to 200 acre-feet/year. Therefore, the water rights issue remains unresolved and will require further discussions with SRP and the U. S. Forest Service.

Figure 5-1

Figure 5-2

The U.S. Forest Service has stated that it would support regulation of the CCC ditch provided that: (1) a government entity commits to maintenance and operation of the ditch in perpetuity; (2) this entity makes a formal application to the U. S. Forest Service for a Special Use Permit; (3) this entity funds or performs a NEPA analysis of the proposed project; and (4) this entity signs a legal agreement to "hold harmless" the U. S. Forest Service with regard to flooding concerns (L. Sears, U S. Forest Service via S. Fitch, ADEQ, elec. comm., 6 June 2000). The government entity that would regulate the ditch has not yet been identified. The diversion of waters, excavation and water control structures would also require permitting through the Coconino County and U.S. Army Corps of Engineers and these offices should be contacted prior to any construction on the CCC ditch.

5.4.2 Costs

The construction of the simple headwall, canal gate, overflow weir system and ditch upgrade are estimated to cost $15,000 to $20,000 and hydrologic monitoring equipment is estimated to cost an additional $3,000. The redirection of water through the weir is likely to require further upgrades to the Stoneman Lake access road in the form of a drain culvert or bypass. A proper drain culvert, including installation, is likely to cost $1,000 to $2,000. Although these capital costs are only moderate, they are less than the projected costs of associated studies and legal costs:

- Study to develop hydrologic formula: $25,000-$35,000
- Environmental Assessment (NEPA documentation): ~$50,000
- Other permits and legal fees: $10,000-$20,000

Thus, the total capital costs of the CCC ditch regulation alternative would be $100,000 to $130,000. Annual costs would include maintenance of the control structure and the labor costs of ditch regulation, which are projected to be less than $10,000 per year.

5.5 Dredging

Dredging is performed in many lakes to increase water depth and also removes nutrients associated with the sediments. Dredging below the photic zone can reduce SAV growth. However, as discussed in section 4.3.4, dredging would be less effective at increasing water depth in Stoneman Lake than most lakes because Stoneman Lake would probably fill to a lower level (elevation) after dredging. Similarly, the high water clarity of Stoneman Lake would make it impractical to dredge deep enough to impart a light limitation to SAV growth. Hydraulic dredging is estimated to cost over $650,000 for only 30-acres of Stoneman Lake, not including costs for permitting or the disposal of dredge spoils. Due to the high costs, short-term impacts to biota and limited benefits of dredging the Stoneman Lake, a full-scale dredging operation is not recommended for Stoneman Lake and is not considered further in this report.

A more cost-effective dredging option for Stoneman Lake may a smaller-scale operation such as use of the Spyder dredge excavator owned by Tite Enterprises. This is a back-hoe type of excavator with four articulated legs that allow it to maneuver in shallow waters. After a visit to Stoneman Lake, it was Tite's opinion that the most abundant silting has occurred in the area immediately downslope from the public parking area (along the northwest shoreline). This is where Tite advised that a limited dredging operation would be the most effective. Tite's estimate for using the Spyder excavator as well as their weed harvester was about \$300.00/hour. This would include limited excavation around the northwest shoreline and harvesting about 50 percent of the lake. If the estimate of \$300.00/hour is applied to four 40-hour work weeks (one month), some limited dredging and harvesting of the lake would cost about \$50,000.

5.6 Septic Systems Upgrades

5.6.1 Tier Determination

Many of the septic systems near Stoneman Lake probably function poorly due their age, construction and intermittent use (D. Cullinane, Circle C Engineering, pers. comm., 11 April 2000). In addition, several drainfields are located within the 100-year floodplain of Stoneman Lake and thus these system pose a potential health risk. Based on interviews with Doug Cullinane, P.E. of Circle C Engineering, septic system upgrades at Stoneman Lake can be broken down into the following three tiers:

Tier I:
Tier I upgrades are described as a limited system with no need for power supply and only limited maintenance. These systems are designed for one average residence discarding only basic household waste. These systems do not have the ability to break down many detergents and chemicals. Each one of these Tier I systems is likely to reduce effluent nitrogen concentrations to about 20 to 30 percent of the influent concentration. These systems are estimated to cost about \$7,000 to \$8,000 each.

Tier II:
The Tier II systems will require power as well as more maintenance than the Tier I tanks. These Tier II systems will contain gray water filter systems that allow them to process *most* chemical wastes. These systems are expected to reduce the effluent nitrogen concentrations to less than 10 mg/l and are likely to cost about \$12,000 to \$13,000 per average residence.

Tier III:
The Tier III systems also require a power source. However, unlike the Tier II systems would not be able to be retrofitted to those systems currently in use. Instead, these systems would require the construction of entirely new tanks. Some of these systems have already been installed at Stoneman Lake for about \$17,000 to \$18,000 each. These systems would effectively remove all nitrogen.

NOTE: These costs are based on an average residence made up of three bedrooms or fewer.

There are essentially no deleterious environmental impacts associated with the upgrade of septic systems. As with all septic systems, the new systems would require permits from the Coconino County Department of

Environmental Health.

5.6.2 "Bright-line" Determination

The notice of proposed rulemaking for type four onsite wastewater treatment facilities (site investigation requirements) was published in the Arizona Administrative Code (A.A.C. R18-9-427) on April 7, 2000. As a result, ADEQ is working to define the 'bright-line" for septic systems at Stoneman Lake. The criteria upon which this distinction is made primarily include the following:

- groundwater table
- soil absorption rate
- soil percolation rate
- surface slope
- surface drainage
- setback distance

For Ponderosa Paradise, the criteria will also consider lake level (USCOE wetland delineation) and spring flow pathways. Two major distinctions have been made:

Within the "bright-line"

1) For new lots: special requirement (i.e., alternative system) beyond conventional septic system
2) Existing lots: require upgrade to alternative systems when conventional systems fail (e.g., Guardian Project)

Outside "bright-line"

1) Develop priority ranking to retrofit existing systems over time

5.7 Aeration and Ciculation

Mechanical or diffused aeration systems can improve water quality by entraining oxygen from the air into the water, thereby increasing D.O. concentrations. This can be accomplished by surface aerators or by hypolimnetic aeration systems that deliver air/oxygen to the lower water column. Artificial circulation is a mechanical means of mixing the lake, thereby eliminated hypoxia caused by vertical stratification. Although these measure would improve D.O. conditions in Stoneman Lake, they would have very large capital costs (>$200,000) both for the aeration/circulation equipment and for power supply (the Stoneman Lake area is not connected to an electric power network). Annual energy and maintenance costs would also be high. Finally, these alternatives have the potential to have detrimental impacts on the aesthetics of Stoneman Lake due to obtrusive and noisy equipment. For these reasons, aeration and artificial circulation are not considered in any more detail in this section.

Figure 5-3

5.8 Regulatory Redesignation

Currently Stoneman Lake is designated as an "aquatic & wildlife-cold water fishery" (A&Wc), with a D.O. criterion of 7.0 mg/L and a pH criterion of 6.5-9.0. The narrative nutrients levels for cold water fisheries is described as "…A surface water shall be free from pollutants in amounts or combinations that inhibit or prohibit the habitation, growth, or propagation of other aquatic life or that impair recreational use." The A&Wc designation is somewhat arbitrary and is based largely on the fact that, like other high-elevation lakes in central Arizona, Stoneman Lake is managed by AGFD as a fishery for cold water species such as northern pike. These species were originally introduced into Stoneman Lake by humans and must be restocked periodically after the lake has gone dry.

It has been suggested that Stoneman Lake should be listed as a warm water fishery (A&Ww), which would reduce the water quality criterion for D.O. to 6 mg/L. Such an action would be of little regulatory benefit because the lake would still experience violations of the D.O., pH and nutrient standards for nutrients. More appropriate would be site-specific water quality criteria or a variance due to natural conditions. Such regulatory actions would be justified because of the weight of scientific evidence that the SAV and water quality problems of Stoneman Lake would persist even if the watershed were completely forested. Such evidence includes the following:

- Geologic cores in Stoneman Lake show abundant SAV pollen dating back to 1,500 years before present.
- Abundant SAV was observed in the lake in the 1930s, when there was very little development.
- Model results (see section 4.1) demonstrate the importance of low flushing rates and internal recycling in Stoneman Lake in controlling nutrient concentrations, as opposed to high external loads.
- Model results (see section 4.2) predict abundant SAV growth and associated hypoxia even if all anthropogenic loads were removed.

Of course, site-specific standards or natural variances alone would do nothing to protect or enhance the recreational uses, wildlife uses, or the aesthetics of Stoneman Lake and so this option would be best pursued in conjunction with other alternatives described in this report. However, such regulatory adjustments would properly acknowledge the impracticality of consistently meeting A&Wc water quality criteria in a clear, shallow, closed lake.

6.0 ALTERNATIVES SUMMARY AND RECOMMENDATION

Table 6-1 provides a summary of the costs and benefits of the seven alternatives for Stoneman Lake addressed in this report. The alternatives are compared in this section with regard to water quality benefit, technical feasibility, regulatory feasibility and cost.

6.1 Water Quality Benefits

Of the seven alternatives, only CCC ditch regulation and aeration/artificial circulation can clearly be predicted to provide high water quality benefits (Table 6-1) to Stoneman Lake. All of the alternatives that involve SAV removal or growth prevention are labeled as medium in this regard due to the possibility of a mixed beneficial/detrimental response. Modeling suggests that these alternatives have the potential to greatly increase algal growth in Stoneman Lake without reducing BOD production. However, the removal of the SAV canopy has the potential to improve vertical mixing and thus provide more oxygen to the entire water column. Septic systems upgrades are labeled as medium with regard to water quality benefits because they would reduce the potential for algal growth in Stoneman Lake and also reduce health risks associated with pathogens. SAV cutting would provide a low water quality benefit because it would exacerbate D.O. impairments.

6.2 Technical Feasibility

Ditch regulation, pesticide application, biological controls and septic system upgrades are all designated as have a high technical feasibility (Table 6-1). Although these alternatives involved certain technical challenges (e.g., development of a hydrologic formula for ditch regulation), such challenges could be met with proper studies and careful planning. Harvesting and cutting are designated as having medium technical feasibility only because the shallowness of Stoneman Lake might prevent access of the equipment to much of the lake during certain seasons. Hydraulic dredging has a low technical feasibility due to the difficulty of equipment access and spoils disposal. Aeration/circulation has a low technical feasibility due to the lack of power supply.

6.3 Regulatory Feasibility

All of the alternatives have a high regulatory feasibility with the exception of ditch regulation and dredging (Table 6-1). Ditch regulation is designated as have a medium regulatory feasibility due to the uncertainty with regard to water rights and permitting by the Corps of Engineers and the U.S. Forest Service. Dredging has a ‘low’ regulatory feasibility due to the potential for wetland impacts.

6.4 Costs

Costs were compared by estimation of the equivalent uniform annual costs (EUACs) of each alternative. Due to the wide range and uncertainties in some of the cost estimates, these costs are tabulated as symbols ($, $$ and $$$) indicating whether the alternative falls in a low (<$5,000), moderate ($5,000-$15,000), or high (>$15,000) range of EUAC (Table 6-1). Most of the

Table 6-1

alternatives fall in the moderate ($$) category. Although ditch regulation has a much higher capital cost than alternatives such as harvesting, the annual costs of this alternative are lower and so the EUAC is moderate. Biological control was the only 'low' cost alternative, partially due to the relatively long life span of carp (six years).

Despite the long effective life of dredging, the high capital costs of dredging caused this alternative to receive a 'high' cost rating. Both capital and annual energy/maintenance costs resulted in as 'high' cost rating for aeration/artificial circulation.

6.5 Overall Comparison

Unlike any other alternative, regulation of the CCC ditch is predicted to provide a high, long-term water quality benefit at a moderate cost. In addition to improving D.O., ditch regulation would help prevent the lake from going dry. The major challenges facing this alternative are not technical but regulatory and legal. Specifically, the major challenges are to resolve the water rights issue, identify a government entity willing and able to assume a leadership role and to obtain the necessary permits.

The different methods of removing SAV also have the potential to significantly improve water quality in Stoneman Lake by the enhancement of vertical mixing. These alternatives will also improve the recreational uses and aesthetics of the lake. Although model results indicate the potential for abundant algal growth, the actual algal response will not be known until one of the SAV removal scenarios is implemented. The risk of complete conversion to an algae-dominated lake could be minimized by harvesting only a portion of the lake while monitoring the effect on algal growth and vertical mixing. If such an exercise indicated that SAV removal would provide a net benefit to the uses of Stoneman Lake, biological controls would be the most cost-effective long-term means of reducing SAV growth.

Septic system upgrades are not predicted to cause short-term changes in the water quality or primary production of Stoneman Lake. However, this alternative would provide modest reductions in algal growth in the event that Stoneman Lake converted to an algal-dominated system. In the long term, this alternative could reduce the amount of nutrients (particularly nitrogen) in both the water column and sediment and thus might cause some reduction in SAV growth rates. The reduction of risk of pathogen transmittal is the primary short-term benefit of septic system upgrades.

Due to high costs and feasibility problems, dredging and aeration/circulation are not practical for Stoneman Lake. The exception to this statement would be the use of a Spyder dredger to deepen small portions of the lake, such as areas affected by siltation near the boat ramp.

Other non-point source reduction alternatives were not modeled or otherwise considered in this study because the watershed is mostly forested and the impoundments on the east side of the lake will capture most of the particulates in runoff from the developed area. Similarly, the lake is surrounded by mats of emergent vegetation that reduce non-point source loading to the lake. However, this should not preclude the implementation of site-specific best management practices (BMPs) to reduce erosion and non-point source pollution, where such problems are identified (e.g., the boat ramp area).

6.6 Tmdl Allocation

ADEQ has determined that every attempt should be made to preserve the character and water quality of Arizona's only natural lake. The study demonstrated that Stoneman Lake is an elastic ecosystem, very much at the mercy of climatic variables. However, there appears to be unanimous support for maintenance of the system *as a lake*, i.e., to stabilize the water level as much as possible and to conduct selective weed harvesting for better water circulation/aeration.

The preferred TMDL alternatives for achieving water quality standards are:

1) Reopen, maintain and control the supplemental CCC ditch (maintain maximum pool level)

2) Establish a harvesting schedule for the lake (reduce SAV in 15% increments)

3) Develop a monthly sampling plan:

- Responsbilities shared between ADEQ, AGFD and property owners
- Data will be adequate to evaluate designated use attainment
- ADEQ & AGFD will conduct a series of diurnal monitoring events during the SAV growing season; monthly monitoring will be done otherwise
- Property owners will measurement lake level (staff gage), precipitation (rain gage), water clarity (Secchi depth) and percent cover of SAV. Field measurements such as temperature, water temperature, cloud cover, pH and dissolved oxygen may be added as interest and resources allow

4) Guardian Project will include septic surveys and replacement/repair of systems determined to be most in need, as well as residential and recreational BMPs to reduce runoff from both private and forest land.

While other aspects of TMDL implementation will be undertaken immediately, r eopening the CCC ditch will likely take more time, perhaps 2-3 years. The U.S. Forest Service has indicted that a new NEPA will need to be done. In the meantime, increased monitoring will better define expectations for the system in the absence of the ditch water. These data can then be compared to data obtained after the ditch is opened. If, however, it becomes clear within the first three years that the option to reopen the ditch must be discarded, the data collected under this TMDL will be evaluated for 1) site-specific standards set for pH, DO and narrative nutrients and/or 2) refined designated uses.

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